INVESTIGATIONS OF AN ELECTRICAL GLOW DISCHARGE, WHEN INSERTED IN SUPERSONIC AIRFLOW, TO DETERMINE ITS DEPENDENCE ON PRESSURE AND VELOCITY

by

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SUMMARY

It has been found in this preliminary investigation that an electrical glow discharge from a sharp point, when inserted in supersonic airflow (M = 1.0 to M = 3.0) is sensitive to the following conditions.

1. The glow current is definitely pressure sensitive at supersonic velocities.
2. Any Mach number change from M = 1 to M = 3 effects the glow current.
3. A greater voltage is required to maintain a given current for larger electrode spacings, a larger size wire, and a positive wire polarity.
4. Platinum wire of 0.003-inch minimum diameter could be used in this investigation because any smaller size wire bent when it was inserted in supersonic airflow.
5. Current flow from 10 to 80 microamperes gives enough flow discharge for this experiment (M = 1.0 to M = 3.0).
6. The shape of the plate and the material from which it is made effect the current flow.
7. The glow changes in size with changes in Mach number.
8. The glow changes in size with change in static pressure.
9. This device adapts itself for use as a static pressure measuring instrument and possibly as a Mach number recorder.

INTRODUCTION

Frank David Werner[1] in his investigation of the possible utilization of an electrical glow discharge as a means for measuring airflow characteristics, found that the glow current from a sharp point is markedly pressure sensitive, somewhat dependent upon velocity, slightly dependent upon humidity, and apparently not dependent upon ordinary temperatures. His investigation was made through a velocity range from zero to 400 feet per second or a Mach number range of from zero to about 0.4.

The primary endeavor in the writer's investigation was to make a preliminary exploration to determine if such a glow would function at all in supersonic airflow, to design apparatus with which an electrical glow discharge from a sharp point could be studied, and also to determine if the glow is pressure or velocity dependent at Mach numbers greater than one. The Mach number range used in this investigation was from 1.0 to 3.0. The facility in which this investigation was carried out was constructed by the writer and Lt. Cdr. F. X. Timmes (graduate student) at the University of Minnesota Aeronautical Laboratories at the Rosemount Research Center, Rosemount, Minnesota.

Since this is the first time an electrical glow discharge from a sharp point has been inserted in supersonic airflow to investigate its dependence on pressures and Mach numbers, it is to be expected that the results obtained will have some experimental errors because of inadequate instrumentation and should be used only as a

guide for later and more elaborate studies. Experience in designing and using equipment to make this investigation should lead to the development of more accurate instrumentation, and to the elimination of some of these errors. However, the general trend of dependence upon Mach number and pressure of the electrical glow discharge from a sharp point will be shown in this investigation.

For this study it was decided to construct a special small size wind tunnel instead of using any of the University's full-scale tunnels. The reason for this decision was the necessity for more flexibility during investigations even though the accuracy of ultimate results may be lowered. Since this was the first use of the sharp point glow discharge in supersonic airflow, many adaptations were more convenient in this setup than in the full-scale tunnel. It is logical that the ultimate check of the data obtained in this tunnel would have to be made in a full-scale tunnel, but that step is beyond the scope of this paper. A single step attempt to use the needle in a full-scale tunnel is shown in the appendix.

The writer is grateful to Professor John D. Akerman for his advice and general direction of the research. Mr. Frank D. Werner was very helpful in the actual design of all the electrical equipment. Professor J. W. Braithwaite was of great assistance in the design and construction of the supersonic wind tunnel.

METHODS

The Laval nozzle was made of lucite for two reasons: First, because of its transparency, through lucite it is possible to observe the electrical glow discharge at different Mach numbers and at different static pressures. Second, since lucite is a good insulator, there was no danger of a current flow to ground through the nozzle if a short occurred. Lucite has proved to be an excellent material to satisfy the above requirements.

The probes were designed to be strong enough so that they would not bend in supersonic airflow. Also, a coating of arcyloid, which is a liquid plastic that hardens in about 48 hours, was used on each probe not only to give more rigidity but also to act as an insulator. The insulatory properties of the coating were essential, especially where the probes were close together, to avoid arcing downstream of the platinum wire. Care was taken not to coat the plate circuit nor the platinum wire with the liquid plastic. Arcyloid proved to be an excellent insulator.

When the plate circuit was positive and the wire negative, measurable current readings were recorded. When the wire was positive and the plate negative, current readings were so small that the electronic equipment designed for these tests did not detect any current flow. Since measurable current readings were recorded when the wire was negative, this type of circuit was used to obtain

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When the plate circuit was positive and the wire negative, measurable current readings were recorded. When the wire was positive and the plate negative, current readings were so small that the electronic equipment designed for these tests did not detect any current flow. Since measurable current readings were recorded when the wire was negative, this type of circuit was used to obtain

the electrical glow discharge current readings. The theory behind this phenomenon is explained extensively in the paper written by Frank David Werner[1]).

The writer has found in this investigation that current readings were obtained up to 350 microamperes at high voltage settings. At these high voltages and currents the electrical glow discharge was almost at an arcing stage; therefore, erratic current readings resulted at this high voltage. For this reason, lower current readings were used in the magnitude of from 60 to 80 microamperes. Enough points were recorded at these lower currents to plot smooth curves as are shown in Figures 2 through 6. From this it can be concluded that the use of lower current will give more stable readings and will give more accurately the trend of events under investigation.

The electronic equipment was designed to give from zero to 10,000 volts positive and from zero to 10,000 volts negative. These two circuits could then be connected in a series to give a range of from zero to 20,000 volts. It was not necessary to use more than 10,000 volts; therefore, it was not necessary to connect the two circuits together. The positive voltage supply was used throughout the entire investigation. The positive lead was connected to the plate circuit which also acted as the static probe while the ground (shield

of co-ax cable) of the circuit was connected to the probe holding the 0.003-inch platinum wire.

EQUIPMENT

Figure 31 shows the wind tunnel nozzle, the manometer board, the electrical equipment, and the probes. Figure 25 is a drawing, to scale, of the wind tunnel. Figure 26 is a scale drawing of the Laval nozzle blocks. Figures 27, 28, and 29 are diagrams of the electrical equipment.

The wind tunnel was supplied with a continuous flow of dry air from a 225-pound-per-square-inch storage tank of 1750 cubic foot capacity. The high pressure air leaves the tank through a 1-inch high pressure steel pipe. A 1-inch gate valve was used to control the air leaving the high pressure storage tank. The air enters the stagnation chamber of the wind tunnel through a 2-inch pipe. A 2-inch globe valve was installed in the 2-inch pipe line for use as a throttling valve. Stagnation pressures in the stagnation chamber were maintained by adjusting the 2-inch throttling valve.

A total head pressure gage was designed as shown in Figure 25. It consisted of a 1/4-inch steel pipe which held a hypodermic needle. This pipe was placed in the stagnation chamber as shown in the scale drawing of the wind tunnel (Figure 25). One end of this steel tube was plugged while the other end was connected to a pressure gage with a scale from zero to 100 pounds per square inch. It was found that this gage gave pressure readings accurate to within one percent of their correct value.

A standard type mercury manometer was constructed and used throughout this investigation to measure static pressure. Figure 31 shows this manometer as it was used to measure static pressures.

Figure 25 shows the bell-mouth entrance to the nozzle. This bell-mouth, made of hydrostone, proved to be very satisfactory. No cracking or chipping of the bell-mouth was noticed at the completion of this investigation.

Figure 26 is a scale drawing of the Laval nozzle blocks. The blocks and side plates were made of lucite and were designed to give a Mach number from 1.0 to 3.0, but a manufacturing error was made which gave a slightly different Mach number. This difference is shown in Figure 1. It can also be seen in Figure 1 that the experimental Mach numbers are slightly less than the theoretical Mach numbers at the same positions in the nozzle, but still gave satisfactory Mach numbers for M = 1.0 to M = 3.1.

The probes, as shown in Figures 30 and 33, were made of 1/4-inch steel tubing. The static probe also acted as the plate of the circuit. A 1/16-inch brass tube was inserted in the upstream end of the static probe. A static hole was drilled in this brass tube 8 diameters from the upstream end. The upstream end of the 1/16-inch brass tube was closed by silver solder and ground to a very fine point. A 1/16-inch solid steel rod was inserted in the upstream end of the glow probe that held the

platinum wire. This upstream end of the solid steel rod was also ground to a very fine point. The 0.003-inch platinum wire was soldered to the upstream sharp end of the steel rod.

Both probes were coated with arcyloid which is a liquid plastic that hardens in about 48 hours. These probes were mounted in lucite holders that were fastened to the probe support. The probe support could be moved back and forth on a steel track, thus enabling the probes to be set at any position desired in the nozzle. Figure 32 shows the probe support and the track on which it could be moved.

The electronic equipment was designed in two separate parts. The circuit for part one is shown in Figure 28. This circuit produced a negative voltage of from zero to 10,000 volts. The circuit for part two is shown in Figure 29. This second circuit produced a positive voltage of from zero to 10,000 volts. Voltmeter and ammeter circuits (Direct Current) were designed as shown and were used to measure currents in microamperes and voltages. All voltmeter and ammeter readings are accurate to within 5 percent of their actual value. Both circuits were installed in the same panel as shown in Figure 31.

TEST PROCEDURE

The static probe, which also acted as the plate circuit of the electrical glow discharge, was inserted in the nozzle at 0.71-inch from the throat with the static hole just opposite the 0.71-inch position. At this position in the nozzle runs were made for different Mach numbers. The stagnation pressure was changed through a range of values to determine the stagnation pressure that produced the approximate theoretical Mach number in the nozzle at the 0.71-inch position. At positions of 1-inch, 2, 3, and 4 inches downstream the same procedure as described above was followed. A curve of the results is shown in Figure 1.

It was found that stagnation pressures of 25, 30, and 40 pounds per square inch gage gave a Mach number of 2.08 at the 1-inch position. Stagnation pressures of 40, 50, and 60 pounds per square inch gage gave a Mach number of 2.44 at the 2-inch position. The 3 and 4-inch positions were probed in the same manner, and Mach numbers of 2.8 and 3.1 were established. Stagnation pressures of 70, 80, and 90 pounds per square inch gage were used at the 3-inch position, and 90, 94, and 100 pounds per square inch were used at the 4-inch position. It was found that below certain stagnation pressures the Mach number at any position could not be obtained. Since the nozzle did not have a diffuser attached to its exit, these high stagnation pressures are to be expected and check very

TEST PROCEDURE

The static probe, which also acted as the plate circuit of the electrolytic glow discharge, was inserted in the nozzle at 0.71-inch from the throat with the static hole just opposite the 0.71-inch position. At this position in the nozzle runs were made for different Mach numbers. The stagnation pressure was changed through a range of values to determine the stagnation pressure that produced the approximate theoretical Mach number in the nozzle at the 0.71-inch position. At positions of 1-inch, 2, 3, and 4 inches essentially the same procedure as described above was followed. A curve of the results is shown in Figure 1.

It was found that stagnation pressures of 25, 30, and 40 pounds per square inch gage gave a Mach number of 2.05 at the 1-inch position. Stagnation pressures of 40, 50, and 60 pounds per square inch gage gave a Mach number of 2.44 at the 2-inch position. The 3 and 4-inch positions were probed in the same manner, and Mach numbers of 2.8 and 3.1 were established. Stagnation pressures of 70, 80, and 90 pounds per square inch gage were used at the 3-inch position, and 90, 95, and 100 pounds per square inch were used at the 4-inch position. It was found that below certain stagnation pressures the Mach number at any position could not be obtained. Since the nozzle did not have a diffuser attached to its exit, these high stagnation pressures were to be expected and agree very

closely to those given in reference 5.

After the static probe Mach number calibration (Figure 1) was made at the various positions in the nozzle, the probe that held the small platinum wire was placed in position. The 0.003-inch platinum wire on this probe was lined up just opposite the static hole in the static probe. With the wire and plate at 0.25-inch spacing between them inserted in the nozzle at the various positions, runs were made as described in the preceding paragraph. Using this configuration, it was found that the same static pressures as obtained with the static probe alone were obtained at any position using corresponding stagnation pressures, thus showing no effect of the glow probe on static pressure and Mach number at locations under investigation.

With the probe spacing of 0.25-inch and the stagnation pressures necessary to produce the Mach number at any given position, runs were made at the various positions in the tunnel. The same procedure was followed for a 0.125-inch spacing. Ammeter and voltmeter readings were recorded during each run.

Since runs were made as rapidly as possible, it was assumed that for any run the temperature remained constant. Also, dry air (-40° F.) was used throughout the investigation.

A vacuum jar was used to determine pressure effect on the glow discharge at zero Mach number. The

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Since runs were made as rapidly as possible, it was assumed that for any run the temperature remained constant. Also, dry air (-40° F.) was used throughout the investigation.

A vacuum jet was used to determine pressure effect on the glow discharge at zero Mach number. The

plate and wire used in the vacuum jar were made of the same material and were the same size. Various absolute pressures were maintained in the jar, and ammeter and voltmeter readings were obtained. Dry air, often ventilated to avoid ionization, was used in the vacuum jar. Figure 2 gives data obtained from this test.

TEST DATA (EXPLANATION OF)

Figure 1 shows the Mach number versus the distance along the nozzle. The Mach number was determined by a static probe connected to a mercury manometer. The stagnation pressure was read directly from a pressure gage. If the stagnation pressure, the static pressure, and the barometer reading are known, Mach number can be easily determined. Isentropic flow was assumed upstream and downstream (but not through) the normal shock wave.

Figures 1 through 7 give microamperes versus volts at various Mach numbers ranging from zero to 3.1. The space between the plate and the wire was 0.25-inch. These curves show that the glow discharge is definitely dependent on pressure.

Figures 8 through 12 give absolute pressures versus volts at various current flows. The data for these curves were obtained from the microamperes versus volts curves (Figures 1-7).

The final curve, Figure 13, shows the effect of Mach number. Here microamperes versus volts at constant absolute pressure were plotted. After studying these curves, it can be readily seen that the glow discharge is velocity dependent. It can be seen that all curves from M = zero to M = 2.8 have the same general trend, but the M = 3.1 curve is different. This is probably due to experimental errors and to poor supersonic airflow at the 4-inch position. Nevertheless, all the

curves show the same general trends and indicate that the Mach number has an effect on the electrical glow discharge.

The remaining curves, Figures 13 through 24, show test data under the same condition as above except that the spacing of the plate and wire was reduced to 0.125-inch. Again it can be seen that the electrical glow discharge is pressure and Mach number dependent. However, this time the Mach number curves did not plot in the same sequence. This is partly due to experimental errors, and it is expected that at the 0.125-inch spacing there is some airflow interference between the plate and the wire, even though it did not show up on the static readings. These curves, even though they don't follow in sequence, show a general trend which indicated that the glow discharge is dependent on Mach number.

Figure 34 shows a spark photograph of the nozzle blocks at a Mach number of zero. It can be seen that the channel walls are fogged up; this is due to poor glueing of the side plates to the nozzle blocks, indicating that the glue had run down the walls of the nozzle. The black heavy line below the channel is a tape measuring device for placing probes at exact position in the nozzle.

Figure 35 shows the same nozzle with supersonic airflow at a Mach number of 2.81. Shock waves at the 4-inch position can be seen. Also, at about the 4-inch position the flow starts to separate, and by the time it

reaches the end of the nozzle it appears to have separated almost completely. Due to the cloudy sides of the channel nothing else can be seen.

Figure 36 shows the same nozzle block with supersonic airflow at a Mach number of 2.81, but this time the probes are inserted in the nozzle. The spacing between the plate and wire was 0.25-inch. Here it appears that the probes have helped the flow, but again due to reflection through the top wall of the channel and cloudy channel walls, little of importance can be seen. Even though the flow appears better with the probes inserted, the static probe manometer readings indicated that at the 4-inch position separation and turbulent flow exists.

Since this experimentation was the first exploration of the supersonic flow by means of sharp point glow discharge, the establishment of methods, trends, limitations, and possible expectations for this type of flow study was more important than finality of results. At the start of the investigation it was not possible to predict in which direction to concentrate and, therefore, a flexibility in general of instrumentation was more important than fine accuracy of any one item in particular, but even with this procedure, the accuracy of all test data is limited only by the type of instrumentation used and the accuracy with which it was read. Considering the type of gages and electronic equipment used, an overall

accuracy of all test data is approximately 95 percent.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that an electrical glow discharge when inserted in supersonic airflow has the following characteristics:

1. The glow current is definitely pressure sensitive.
2. The glow current is dependent on velocity -- that is, any Mach number between M = 1 and M = 3 change effects the glow current.
3. A greater voltage is required to maintain a given current for larger electrode spacings, a larger size wire, and positive wire polarities.
4. Platinum wire 0.003-inch diameter could be used in this investigation because any smaller size wire bent when it was inserted in supersonic airflow.
5. Current flow from 10 to 80 microamperes gives enough glow discharge for this experiment.
6. The shape of the plate and the material from which it is made effect the current flow.
7. The glow changes in size with changes in Mach number.
8. The glow changes in size with change in static pressure.
9. This device adapts itself for use as a static pressure measuring instrument and possibly as a Mach number recorder.

The following recommendations are given below:

1. If lucite nozzle blocks are to be made for this tunnel, it is recommended that great care be taken in the glueing process to give clear and smooth walls.
2. Nozzle blocks should be made by the method of characteristics, thus eliminating the bad flow conditions encountered in the Laval nozzle.

3. An extremely sensitive type of throttling valve be incorporated in the equipment to enable the operator to hold stagnation pressures more closely to the desired value.

4. An accurate means of measuring stagnation pressures be used. It is suggested that an electronic gage (strain gage) be used.

5. A mount holder for the probes should be designed so that it will give good accessibility to a change in spacing of plate and wire.

6. The two probes should be made of a strong insulating material, thus eliminating steel tubing and liquid plastic insulations.

7. A high voltage fuse should be used in the electronic equipment to avoid any voltage leakage and to protect the power supply.

8. A voltmeter and an ammeter circuit should be designed to measure the voltage and the current when the two power supplies are connected in series.

9. A tapered needle to give sharper point and enough strength to withstand air blast may be necessary and if it is not too expensive to manufacture, should be tried in the next experiments.

BIBLIOGRAPHY

1. WERNER, Frank David. "Investigation of the Possible Utilization of an Electrical Glow Discharge as a Means for Measuring Airflow Characteristics". UMAL Research Report 38, Master's thesis, University of Minnesota, 1948.

2. LOEB, L. D. "Fundamental Processes of Electrical Discharge in Gases", John Wiley and Sons, Inc., 1939.

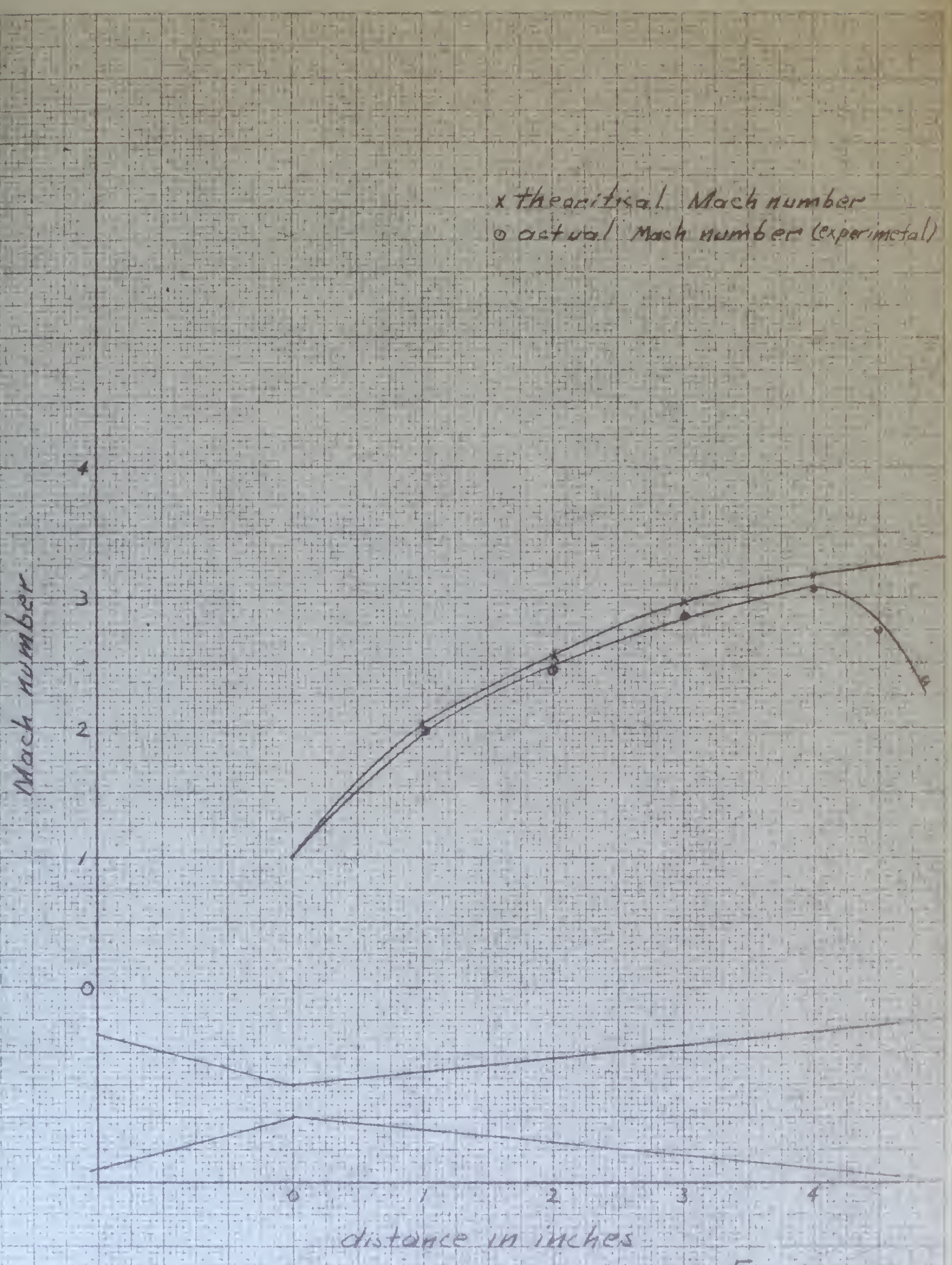
3. COBINE, JAMES DILLON. "Gaseous Conductors", Mc-Graw-Hill Book Company, Inc., 1941.

4. HOAG, J. BARTON. "Basic Radio", D. Van Nostrand Co., Inc., 1942.

5. LIEPMANN, HANS VOLFGANG and PUCKETT, ALLEN E. "Introduction to Aerodynamics of a Compressible Fluid", John Wiley and Sons, Inc., 1947, p. 35.

6. KEENAN, JOSEPH H., and KAYE, JOSEPH. "Gas Tables", John Wiley and Sons, Inc., 1948.

7. NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Technical Note 1428, Notes and Tables for use in the Analysis of Supersonic Flow.



x theoritical Mach number
o actual Mach number (experimetal)
Mach number
4
3
2
1
0
0
1
2
3
4
distance in inches

Fig-1-

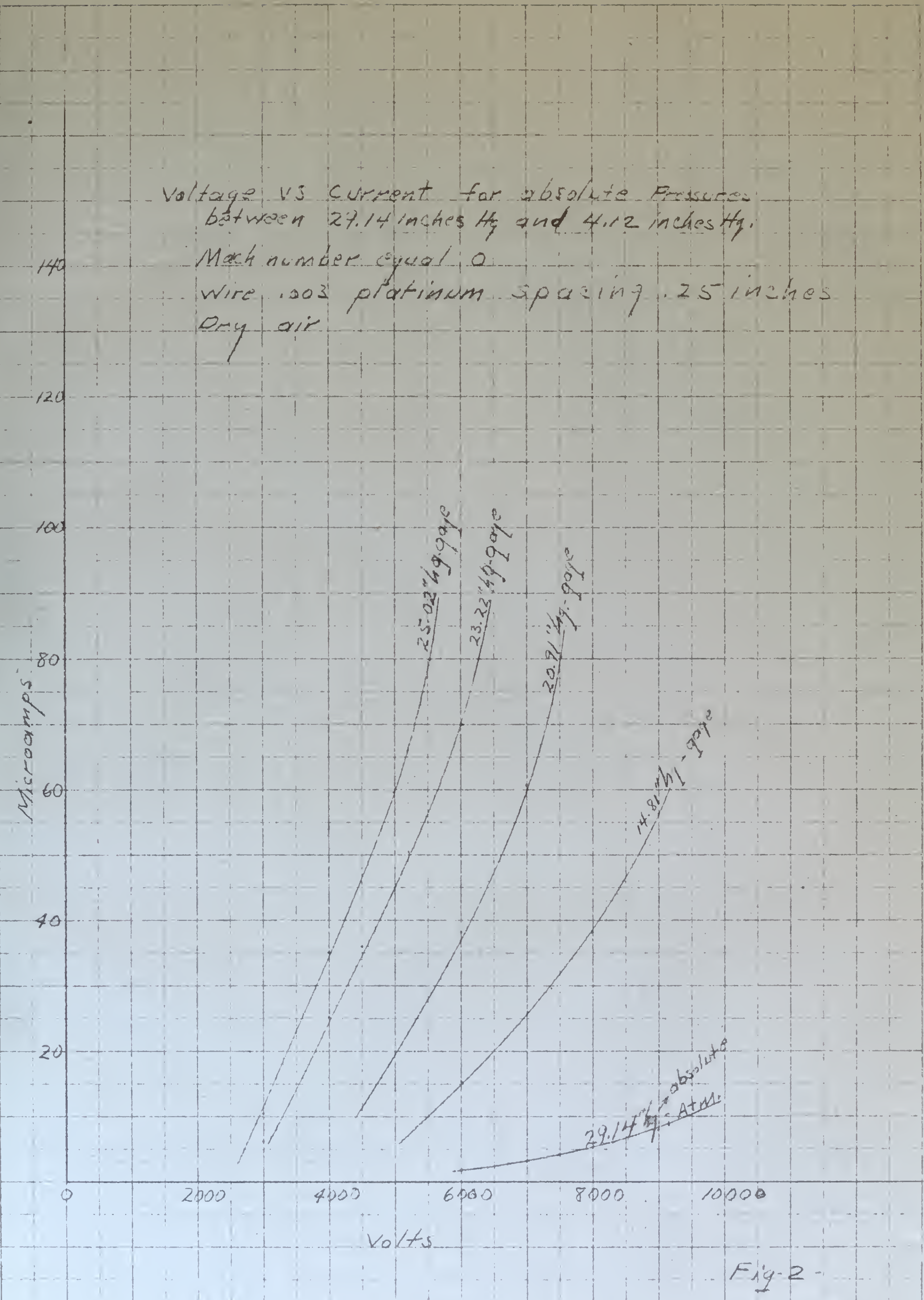
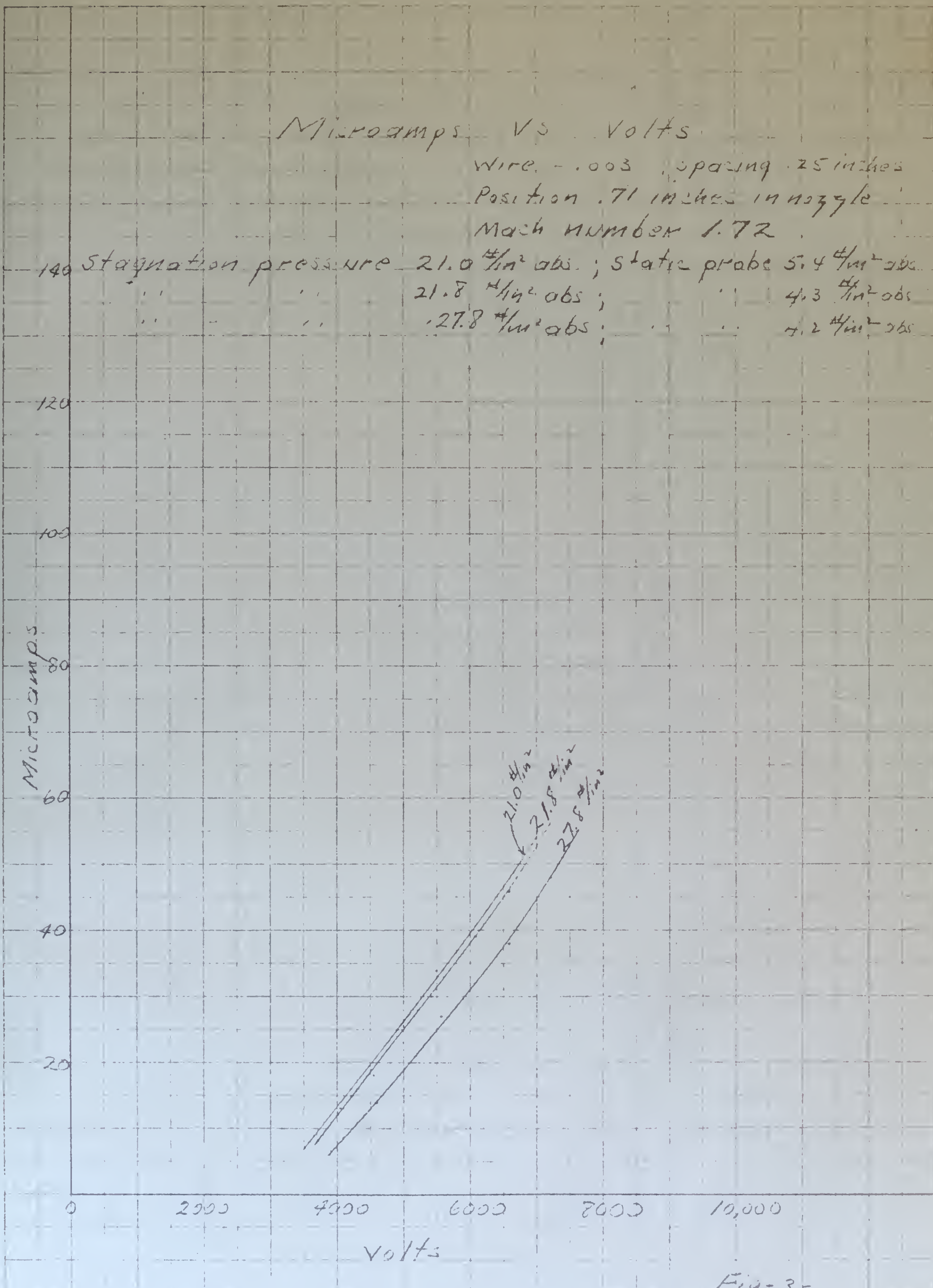
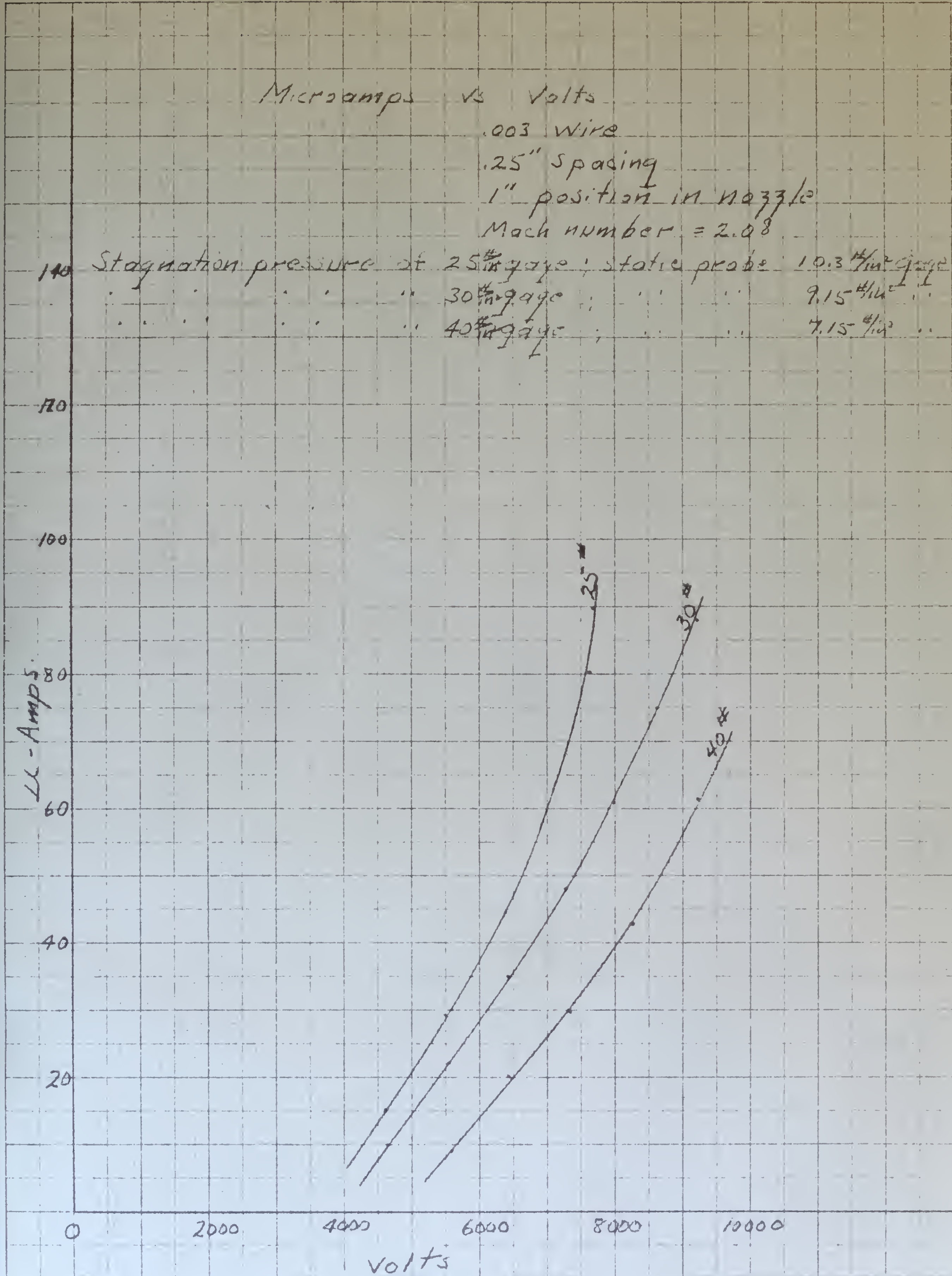

Voltage VS Current for absolute Pressures
between 29.14 inches Hg and 4.12 inches Hg.
Mach number equal 0
Wire .003 platinum spacing .25 inches
Dry air
Microamps
140
120
100
80
60
40
20
0
2000
4000
6000
8000
10000
Volts
25.02" Hg gage
23.22" Hg gage
20.71" Hg gage
14.81" Hg gage
29.14" Hg absolute Atm.

Fig-2-


Microamps VS Volts
Wire - .003 ; spacing .25 inches
Position .71 inches in nozzle
Mach number 1.72
Stagnation pressure 21.0 #/in² abs. ; static probe 5.4 #/in² abs
" " 21.8 #/in² abs ; " 4.3 #/in² abs
" " 27.8 #/in² abs ; " " 4.2 #/in² abs
21.0 #/in²
21.8 #/in²
27.8 #/in²
Microamps
140
120
100
80
60
40
20
0
2000
4000
6000
8000
10,000
Volts
Fig-3-



Microamps vs Volts
.003 Wire
.25" Spacing
1" position in nozzle
Mach number = 2.08
Stagnation pressure at 25#/in² gage ; static probe 10.3#/in² gage
" " " " 30#/in² gage ; " " 9.15#/in² "
" " " " 40#/in² gage ; " " 7.15#/in² "
140
120
100
80
60
40
20
μ-Amps
0
2000
4000
6000
8000
10000
Volts
25#
30#
40#

Fig-4-

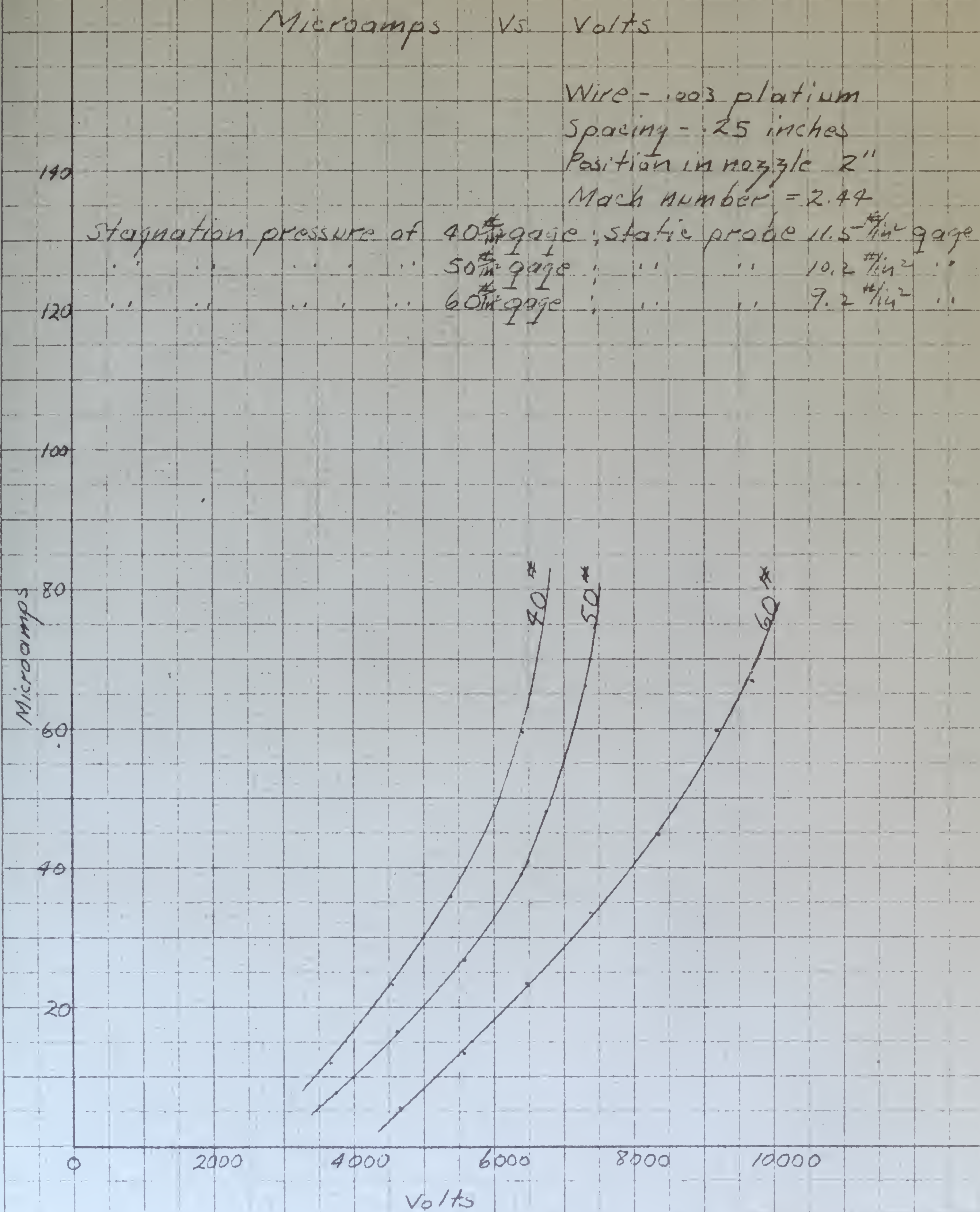

Microamps Vs Volts
Wire - .003 platium
Spacing - .25 inches
Position in nozzle 2"
Mach number = 2.44
Stagnation pressure of 40#/in² gage; static probe 11.5 #/in² gage
" " " " " 50#/in² gage; " " 10.2 #/in² "
" " " " " 60#/in² gage; " " 9.2 #/in² "
140
120
100
80
60
40
20
Microamps
0
2000
4000
6000
8000
10000
Volts
40#
50#
60#

Fig. 5

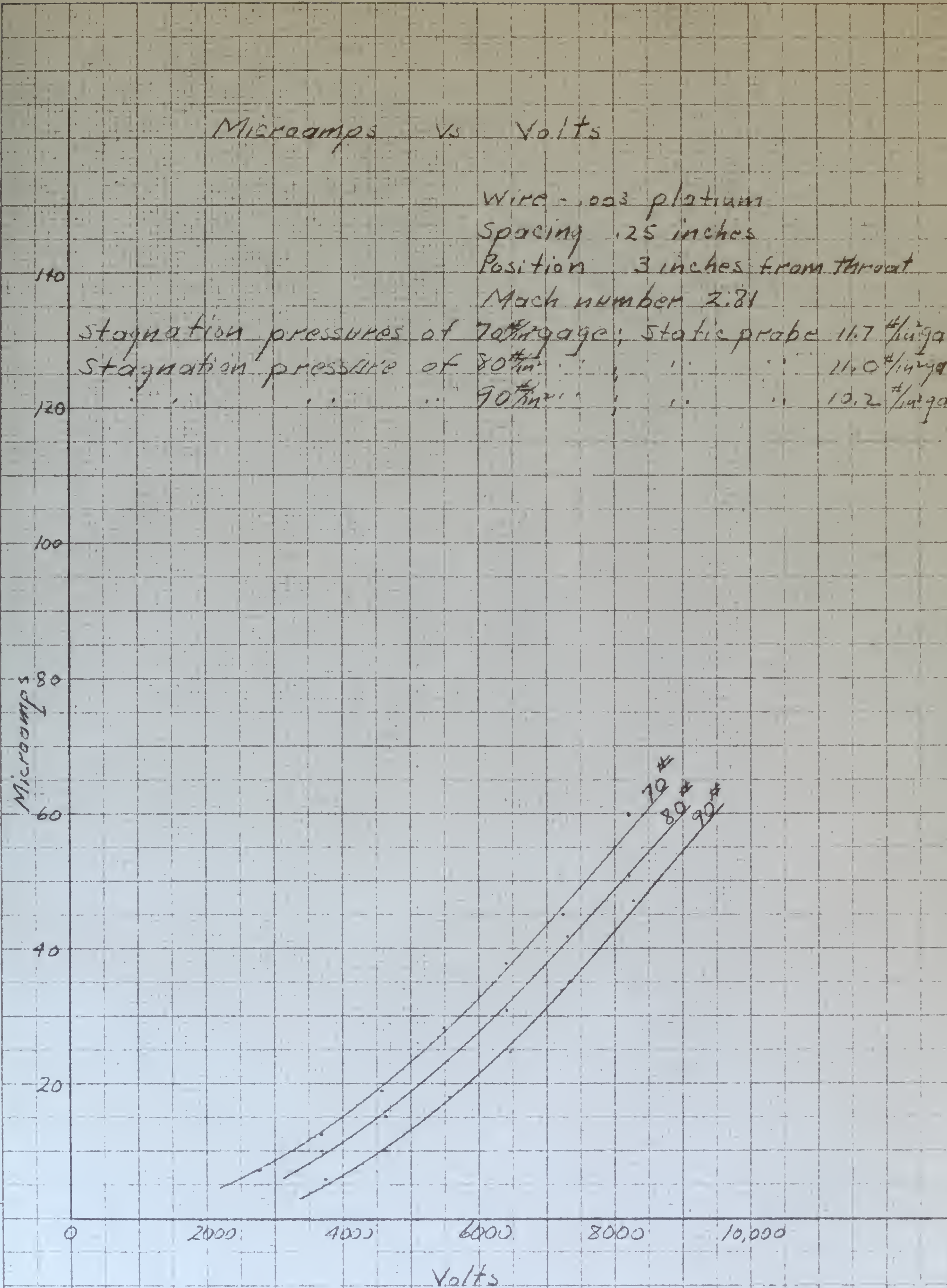

Microamps vs Volts
Wire - .003 platium
Spacing .25 inches
Position 3 inches from throat
Mach number 2.81
stagnation pressures of 70#/in² gage; static probe 11.7 #/in² ga.
Stagnation pressure of 80#/in² " ; " " 11.0 #/in² ga
" " " 90#/in² " ; " " 10.2 #/in² ga
140
120
100
80
60
40
20
0
2000
4000
6000
8000
10,000
Microamps
Volts
70#
80#
90#

Fig -6-

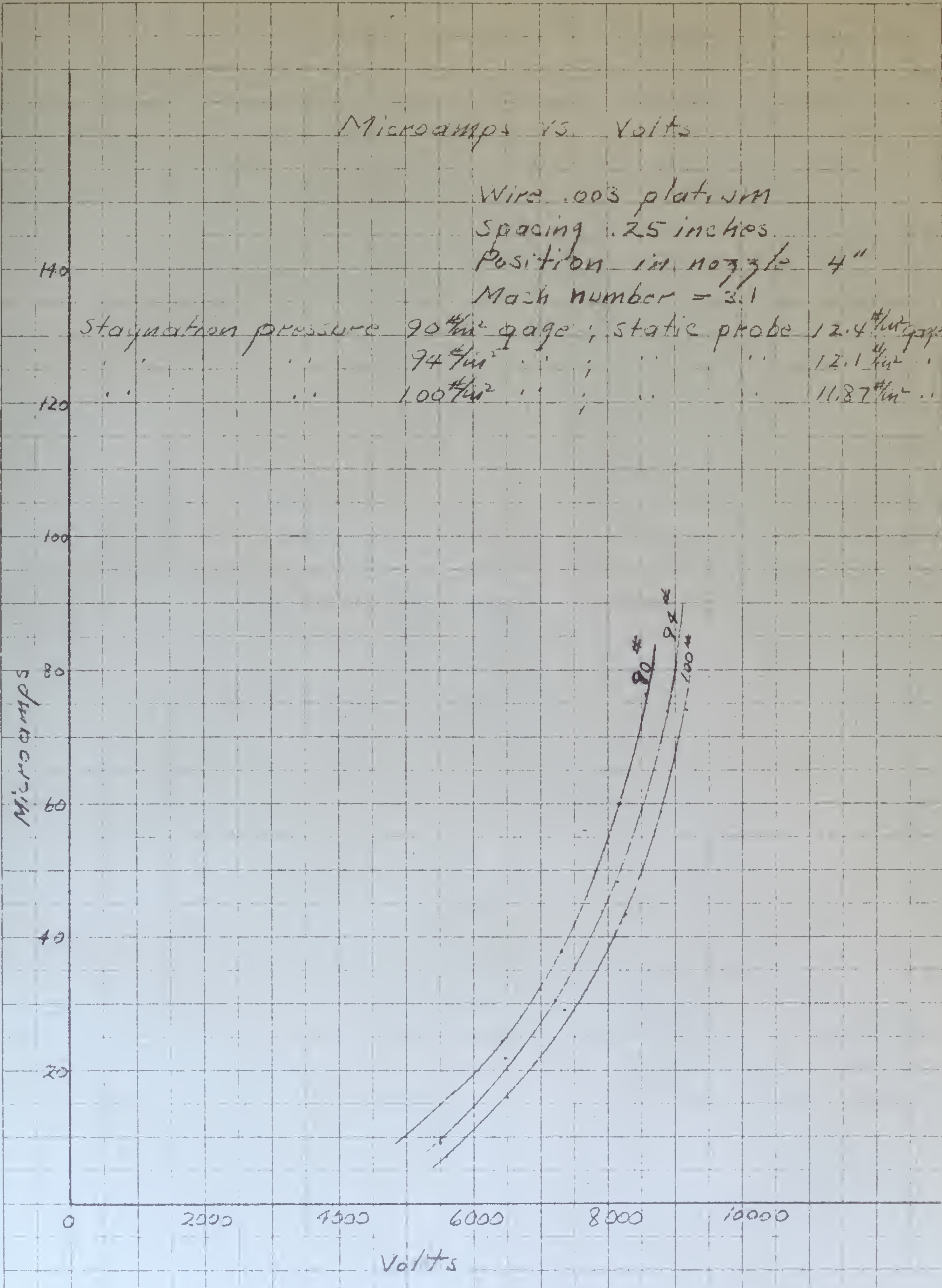
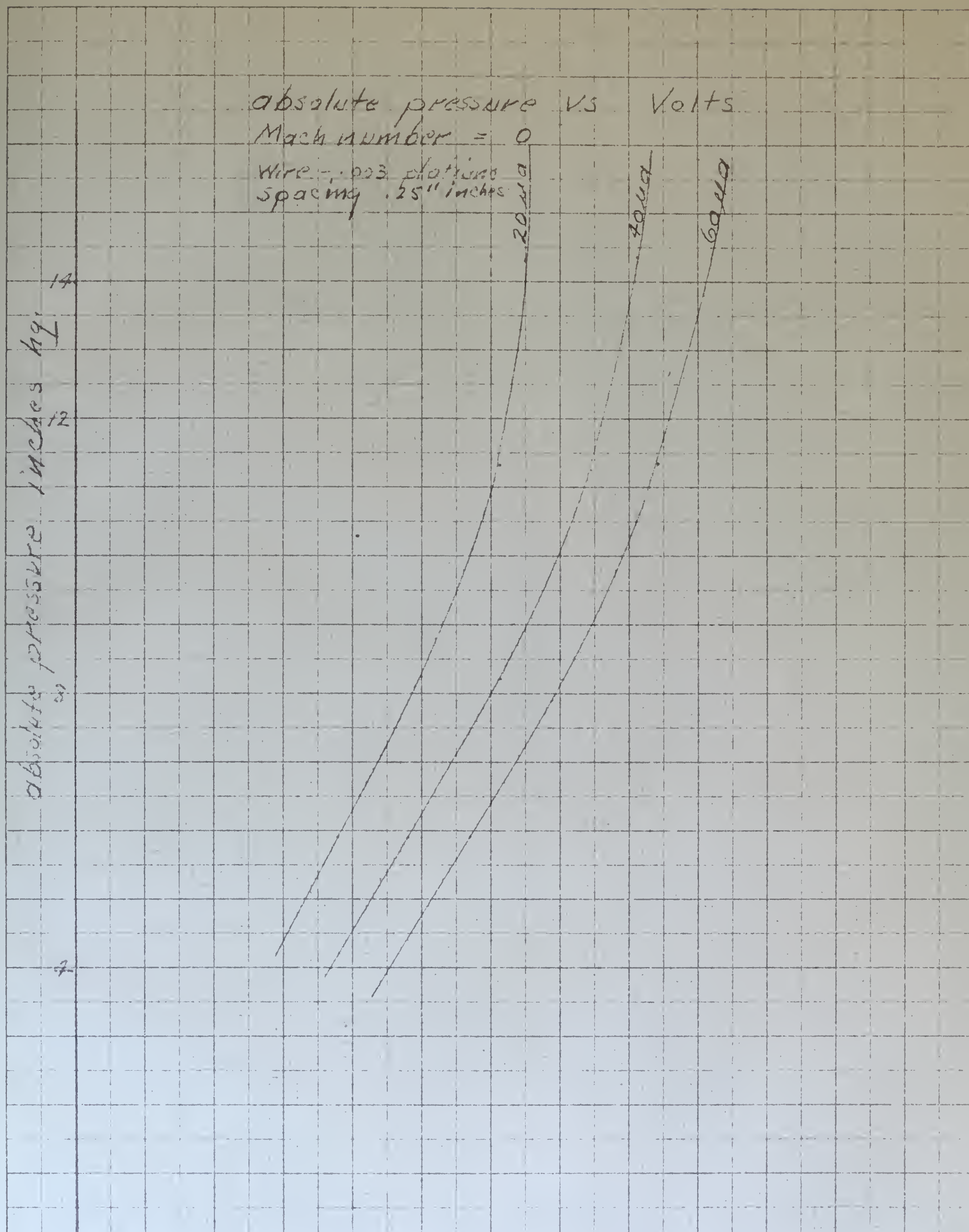

Microamps vs. Volts
Wire .003 platinum
Spacing .25 inches
Position in nozzle 4"
Mach number = 3.1
Stagnation pressure 90#/in² gage ; static probe 12.4#/in² gage
" " 94#/in² " ; " " 12.1#/in² "
" " 100#/in² " ; " " 11.87#/in² "
140
120
100
80
60
40
20
Microamps
0
2000
4000
6000
8000
10000
Volts
90#
94#
100#

Fig. 7.



absolute pressure vs Volts
Mach number = 0
Wire - .003 platinum
spacing .25" inches
20 μa
40 μa
60 μa
absolute pressure inches hg
14
12
4
0
2000
4000
6000
8000
10000
Volts

Fig - 8 -

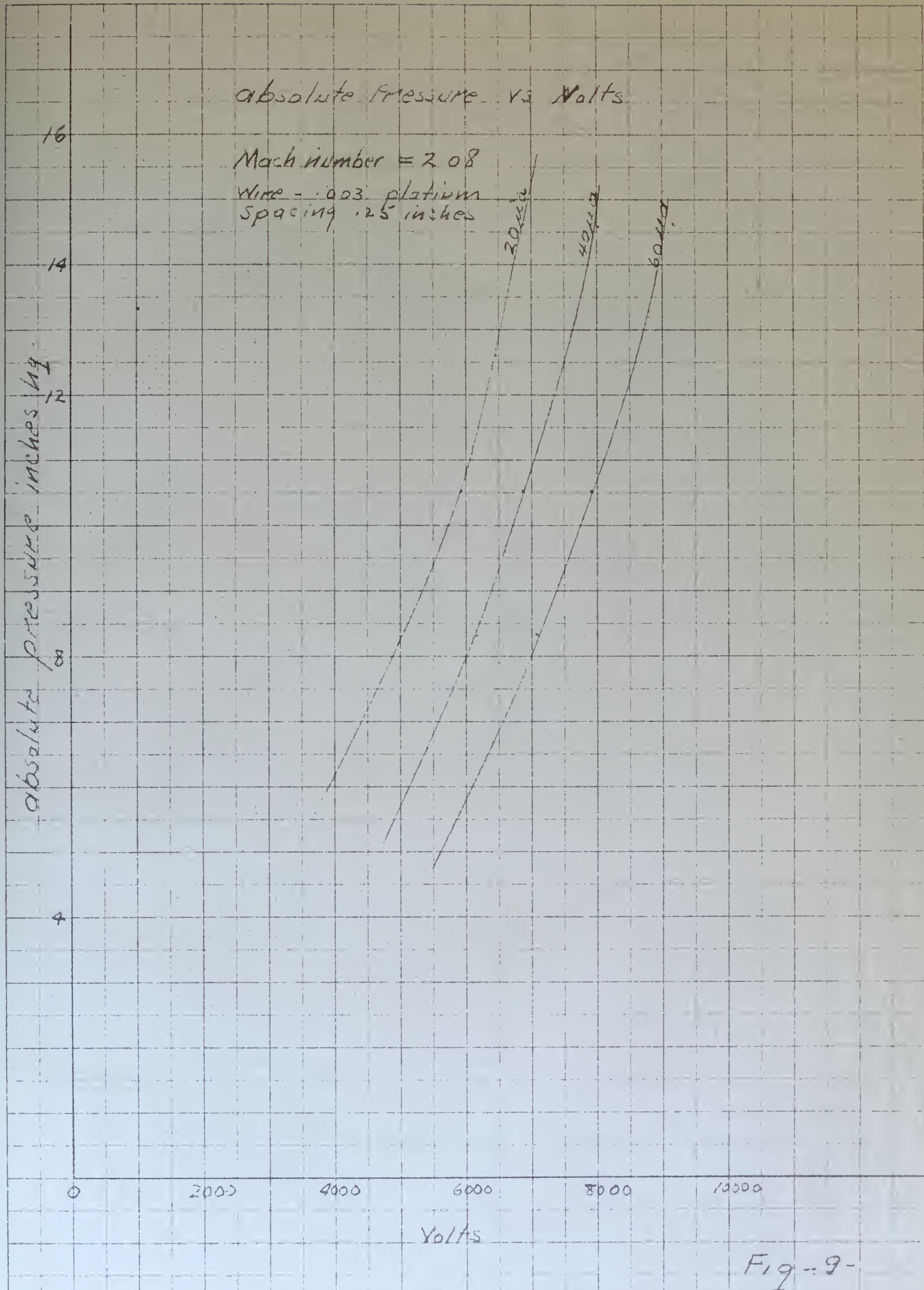

absolute pressure vs Volts
Mach number = 2.08
Wire - .003 platium
Spacing .25 inches
20 ma
40 ma
60 ma
16
14
12
8
4
0
2000
4000
6000
8000
10000
absolute pressure inches hg.
Volts

Fig - 9 -

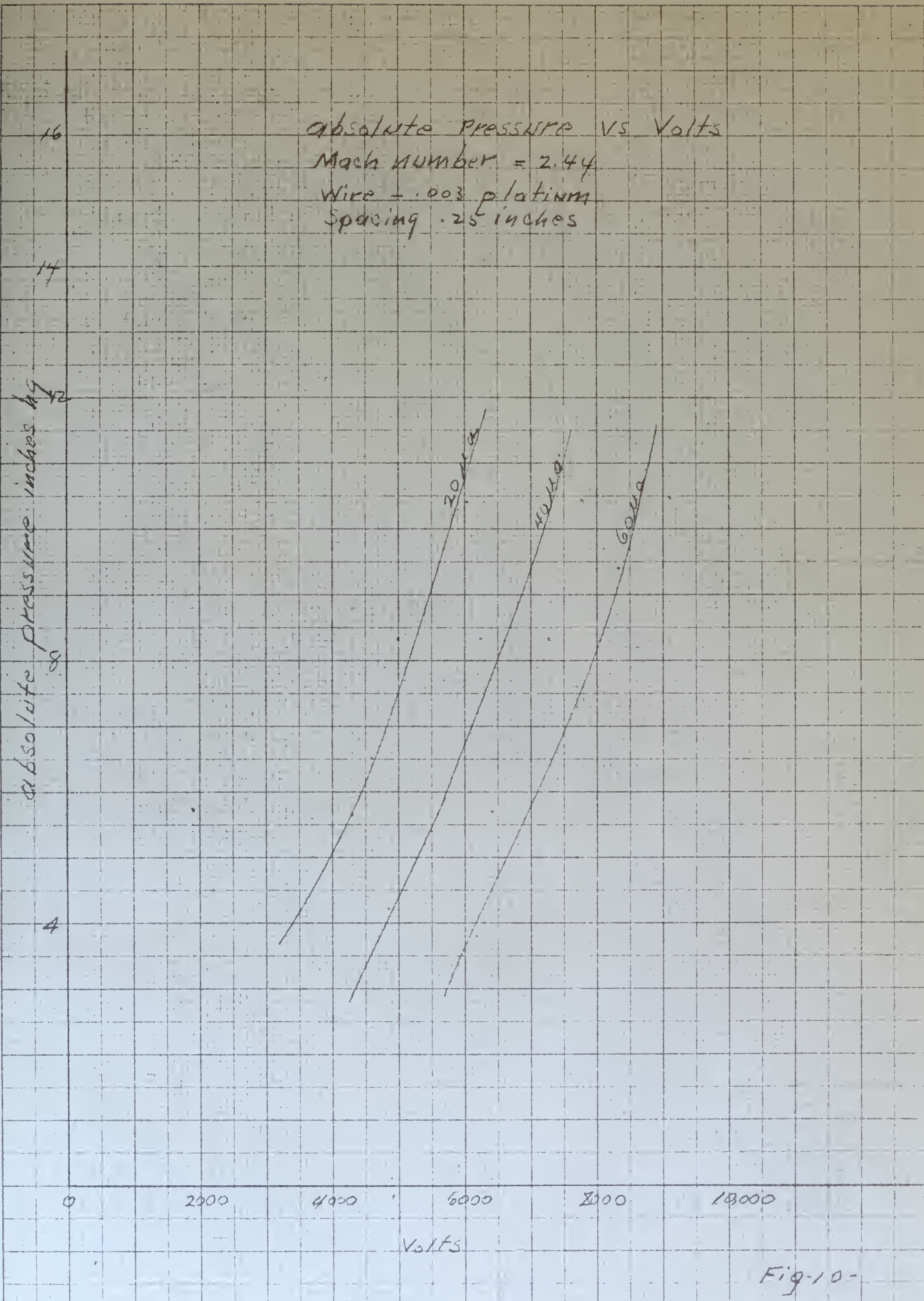

absolute Pressure vs Volts
Mach number = 2.44
Wire - .003 platinum
Spacing .25 inches
absolute pressure inches Hg
16
14
12
8
4
0
2000
4000
6000
8000
10000
Volts
20μa
40μa
60μa

Fig-10-

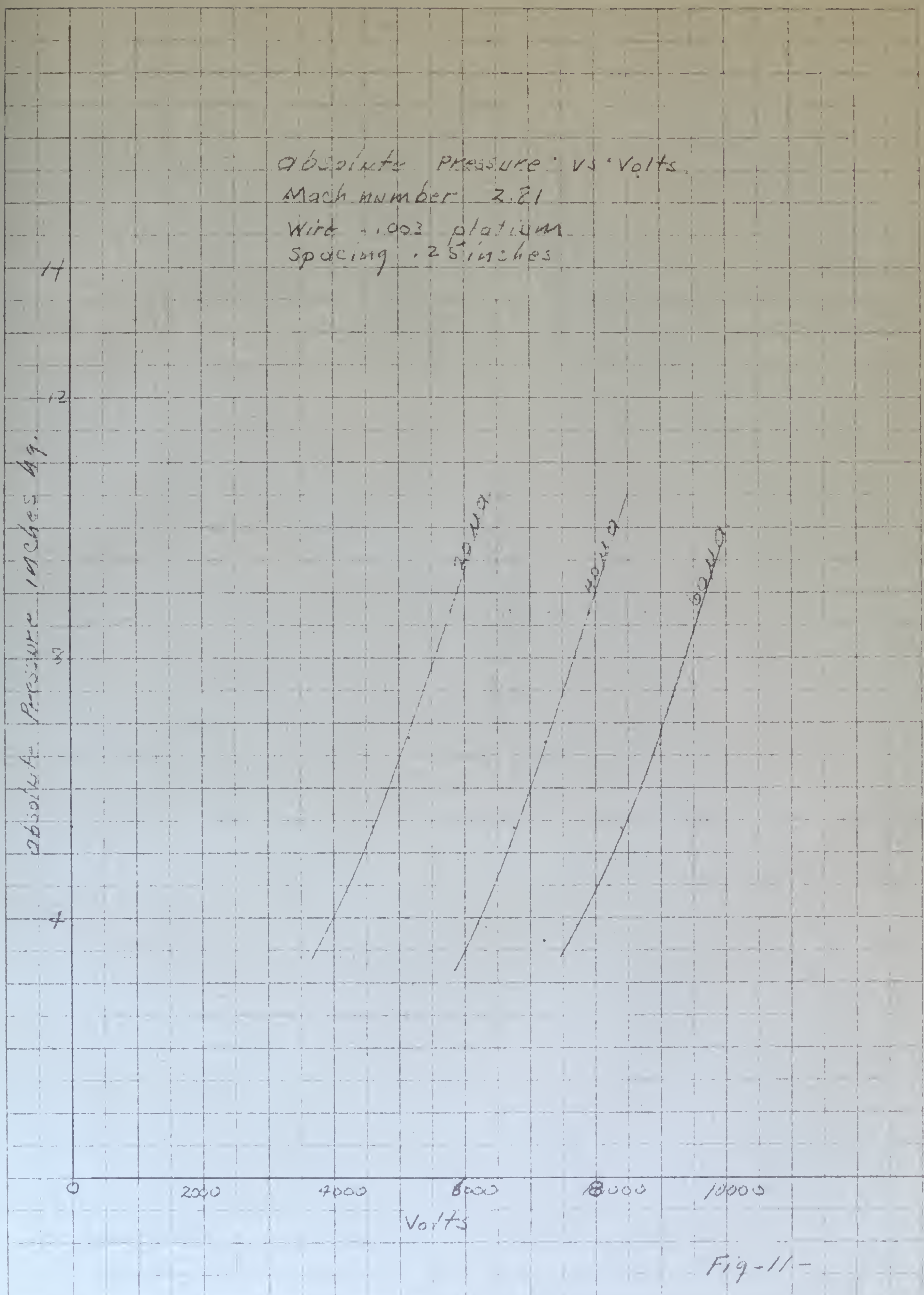

absolute Pressure vs Volts
Mach number 2.81
Wire .003 platium
Spacing .25 inches
absolute Pressure inches Hg.
4
8
12
14
0
2000
4000
6000
8000
10000
Volts
20 Ma
40 Ma
60 Ma

Fig-11-

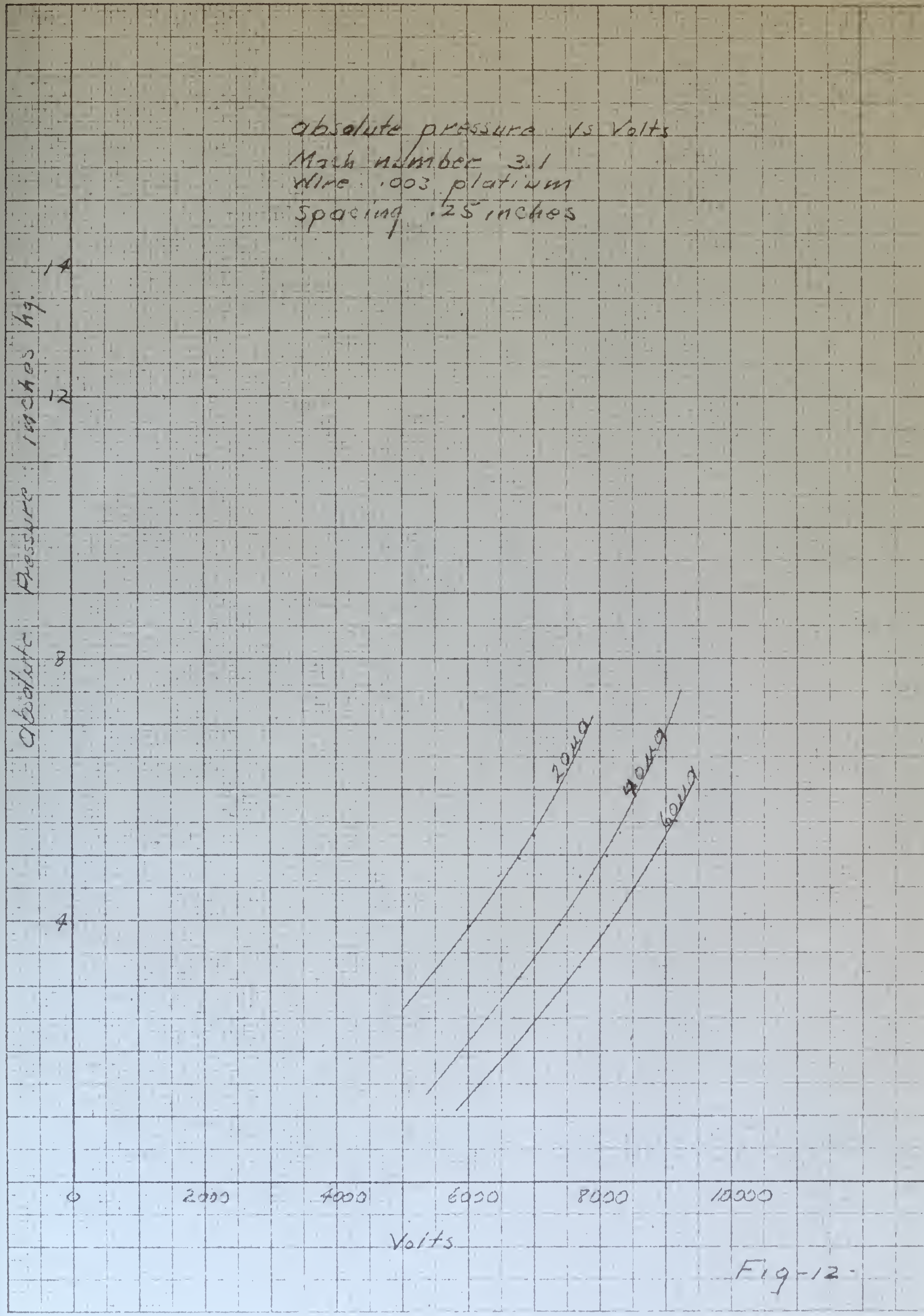

absolute pressure vs Volts
Mach number 3.1
Wire .003 platium
Spacing .25 inches
Absolute Pressure inches hg.
14
12
8
4
0
2000
4000
6000
8000
10000
Volts
20 μa
40 μa
60 μa

Fig-12-

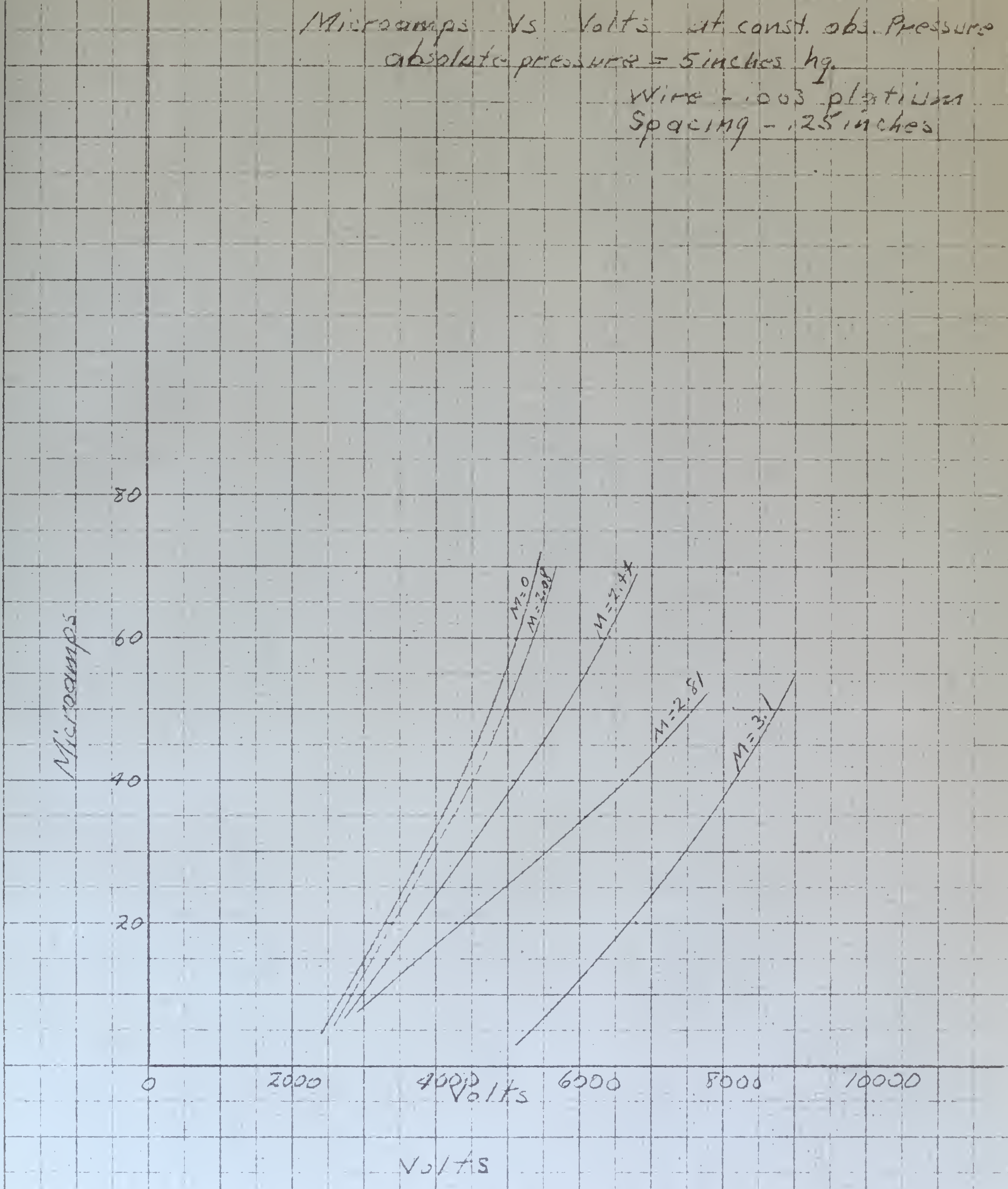

Microamps Vs Volts at const. abs. Pressure
absolute pressure = 5 inches hg.
Wire - .003 platium
Spacing - .25 inches
M=0
M=2.08
M=2.44
M=2.81
M=3.1
Microamps
80
60
40
20
0
2000
4000
6000
8000
10000
Volts
Volts

Fig-13-

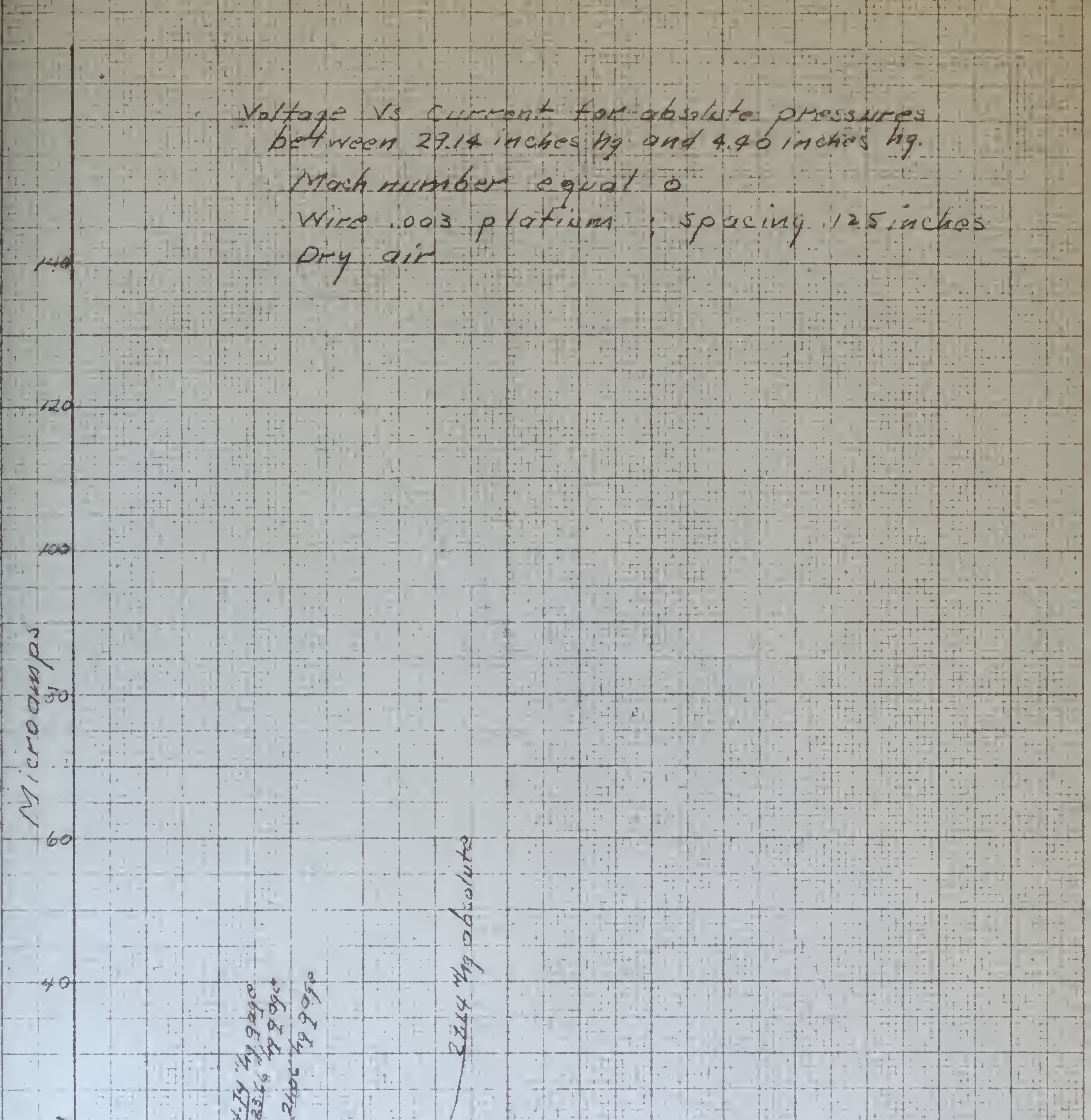

Voltage Vs Current for absolute pressures
between 29.14 inches hg and 4.40 inches hg.
Mach number equal 0
Wire .003 platium ; spacing .125 inches
Dry air
Microamps
140
120
100
80
60
40
20
0
2000
4000
6000
8000
10000
Volts

Fig -14-

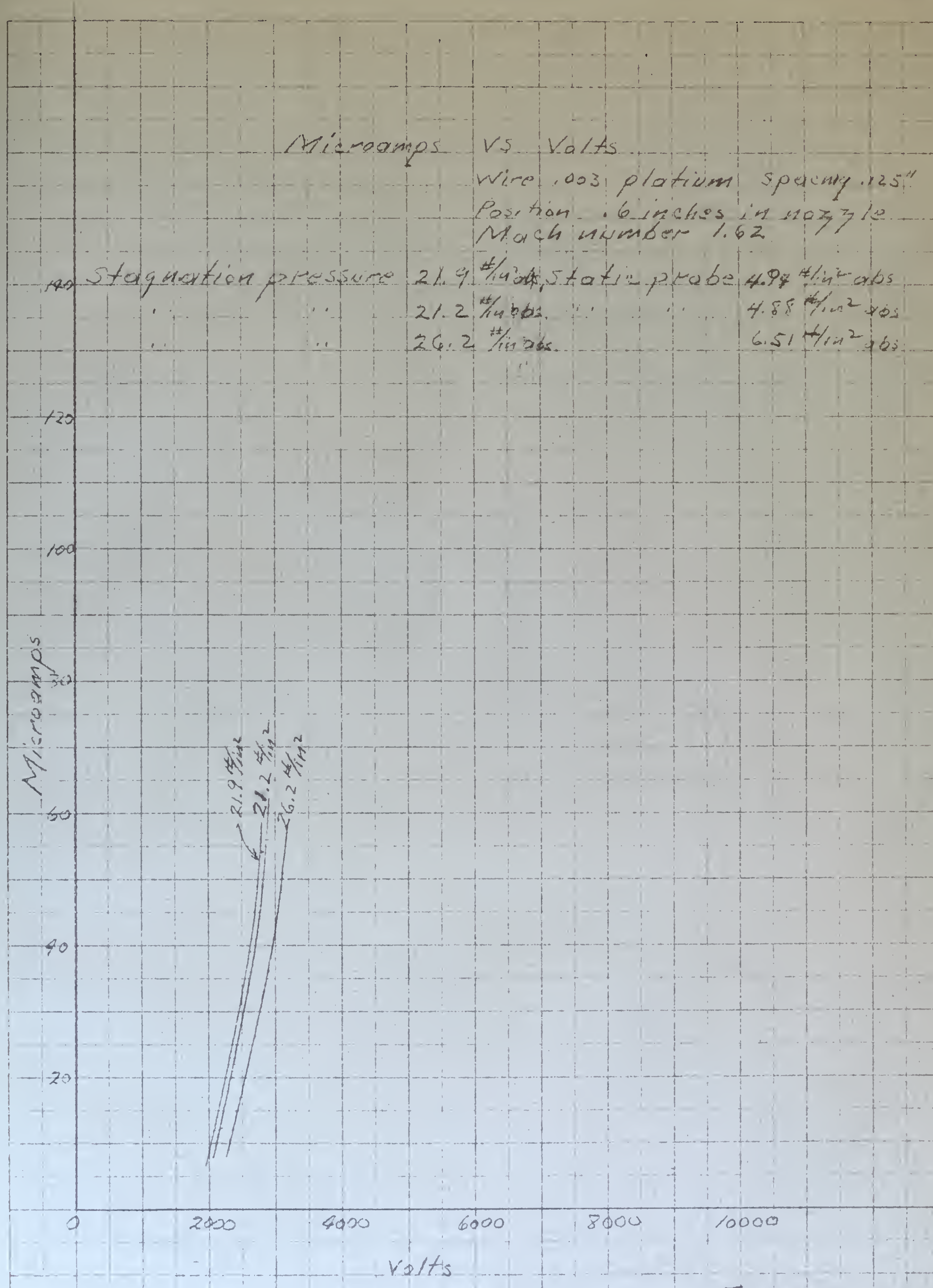
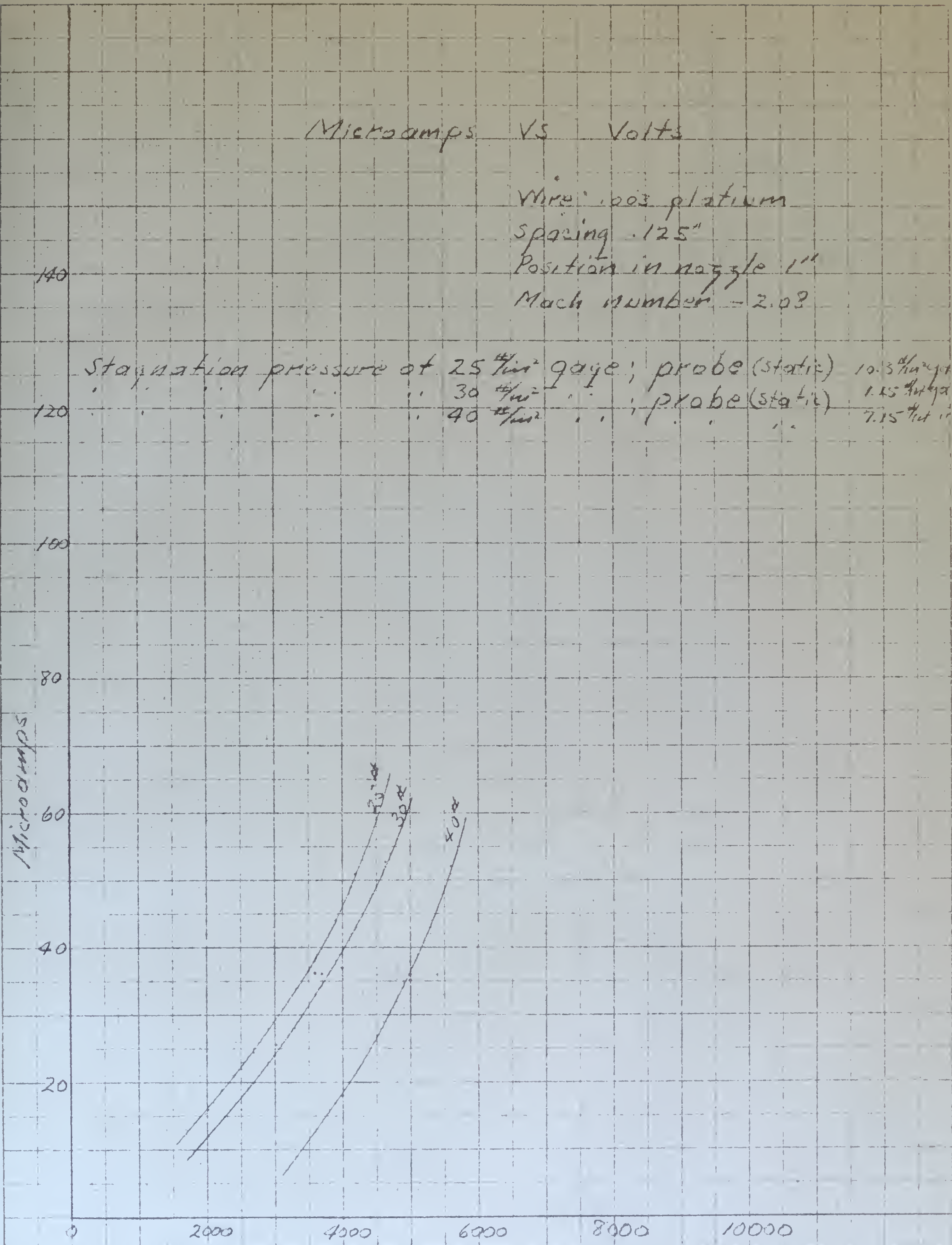

Microamps VS Volts
Wire .003 platium spacing .125"
Position .6 inches in nozzle
Mach number 1.62
Stagnation pressure 21.9 #/in² abs, Static probe 4.94 #/in² abs
" " 21.2 #/in² abs. " " 4.88 #/in² abs
" " 26.2 #/in² abs. 6.51 #/in² abs
140
120
100
80
60
40
20
0
2000
4000
6000
8000
10000
Microamps
Volts
21.9 #/in²
21.2 #/in²
26.2 #/in²

Fig-15-



Microamps VS Volts
Wire .003 platium
Spacing .125"
Position in nozzle 1"
Mach number - 2.03
Stagnation pressure at 25 #/in² gage; probe (static) 10.3 #/in² gage
" " " " 30 #/in² " " ; probe (static) 1.15 #/in² gage
" " " " 40 #/in² " " ; " " " 7.15 #/in² "
140
120
100
80
60
40
20
0
2000
4000
6000
8000
10000
Volts
Microamps
25 #
30 #
40 #

Fig-16-

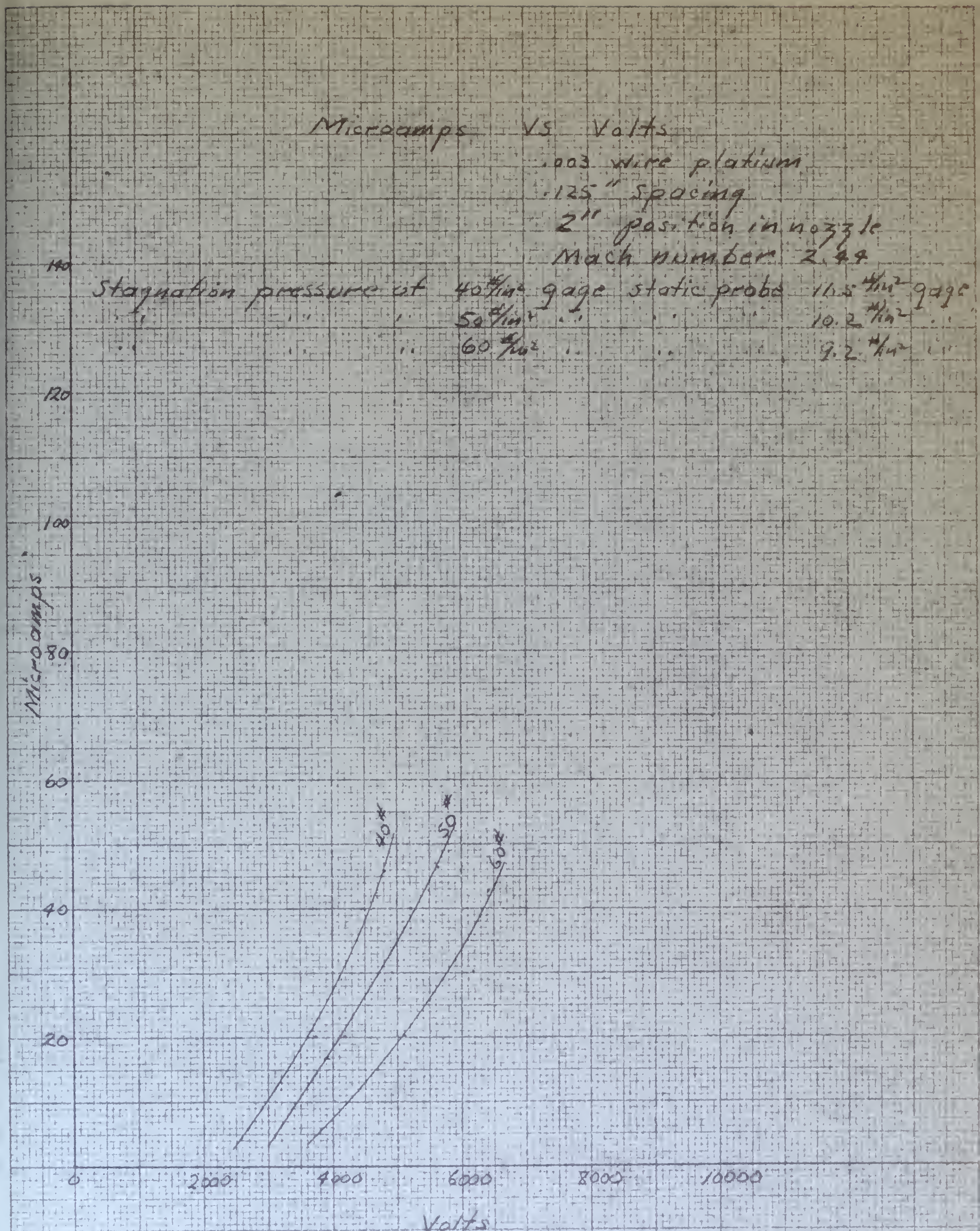

Microamps VS Volts
.003 wire platium
.125" Spacing
2" position in nozzle
Mach number 2.44
Stagnation pressure at 40#/in² gage static probe 11.5 #/in² gage
" " " 50#/in² " " " 10.2 #/in² "
" " " 60#/in² " " " 9.2 #/in² "
40#
50#
60#
140
120
100
80
60
40
20
0
2000
4000
6000
8000
10000
Microamps
Volts

Fig-17-

Microamps vs Volts

Wire .003 platinum
Spacing 1/25
Mach number 2.81
position in nozzle 3"

Stagnation pressure of 70 #/in² gage static probe 11.7 #/in² gage
" " 80 #/in² " " " 11.0 #/in² "
" " 90 #/in² " " " 10.2 #/in² "

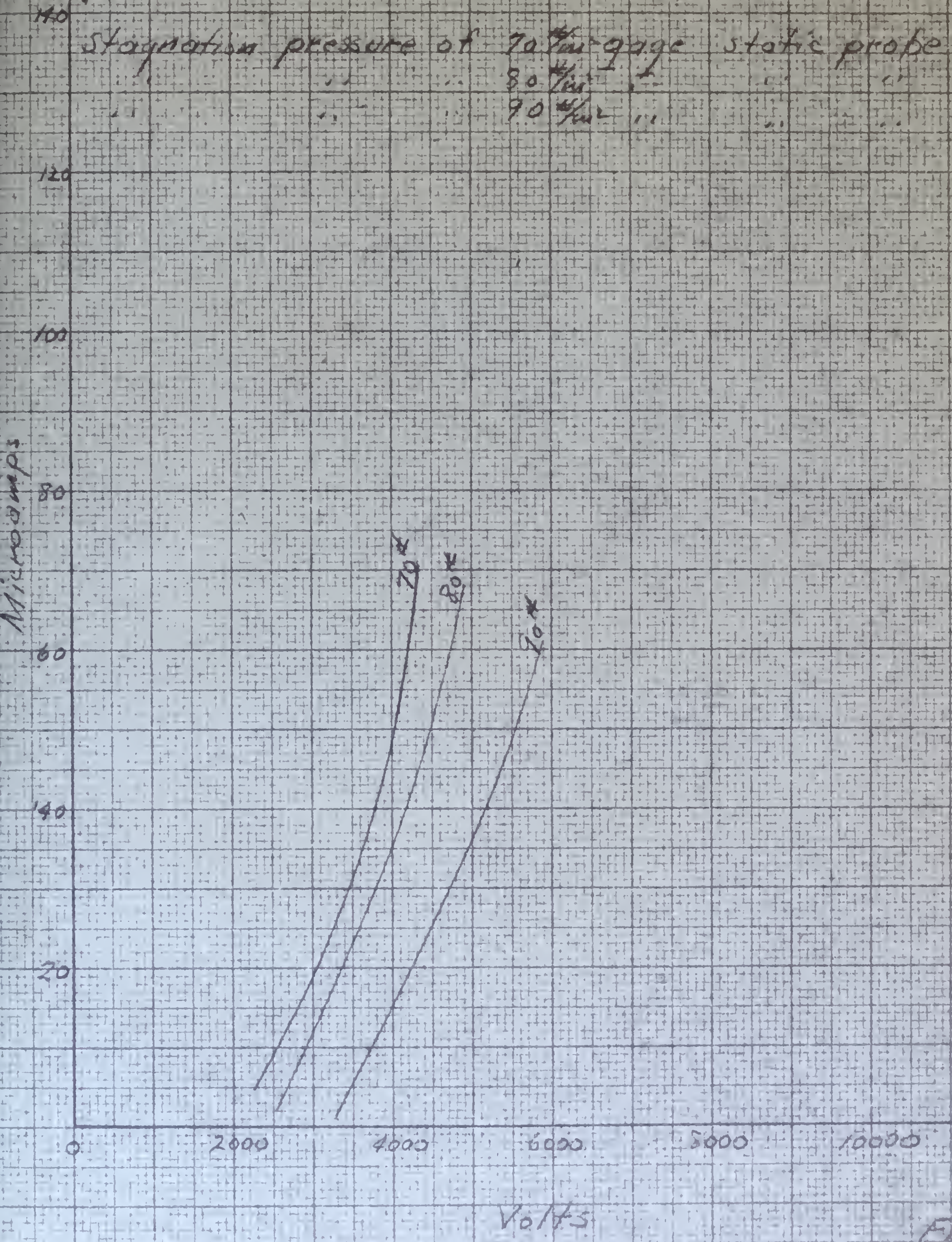


Fig-18-

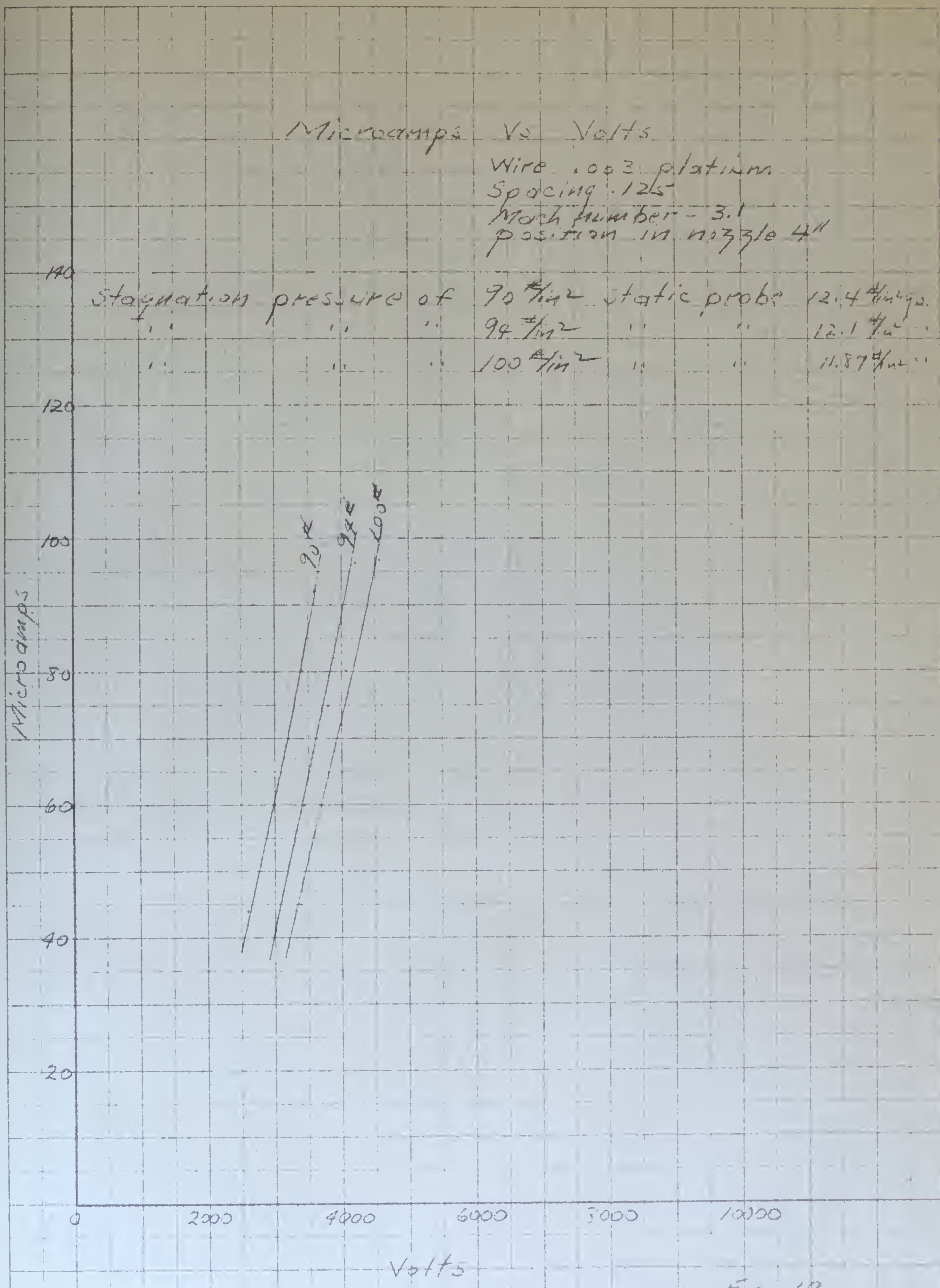

Microamps Vs Volts
Wire .003 platinum
Spacing .125
Mach number - 3.1
position in nozzle 4"
Stagnation pressure of 90 #/in² static probe 12.4 #/in² ga.
" " " 94 #/in² " " 12.1 #/in² "
" " " 100 #/in² " " 11.87 #/in² "
90#
94#
100#
140
120
100
80
60
40
20
Microamps
0
2000
4000
6000
8000
10000
Volts

Fig-19-

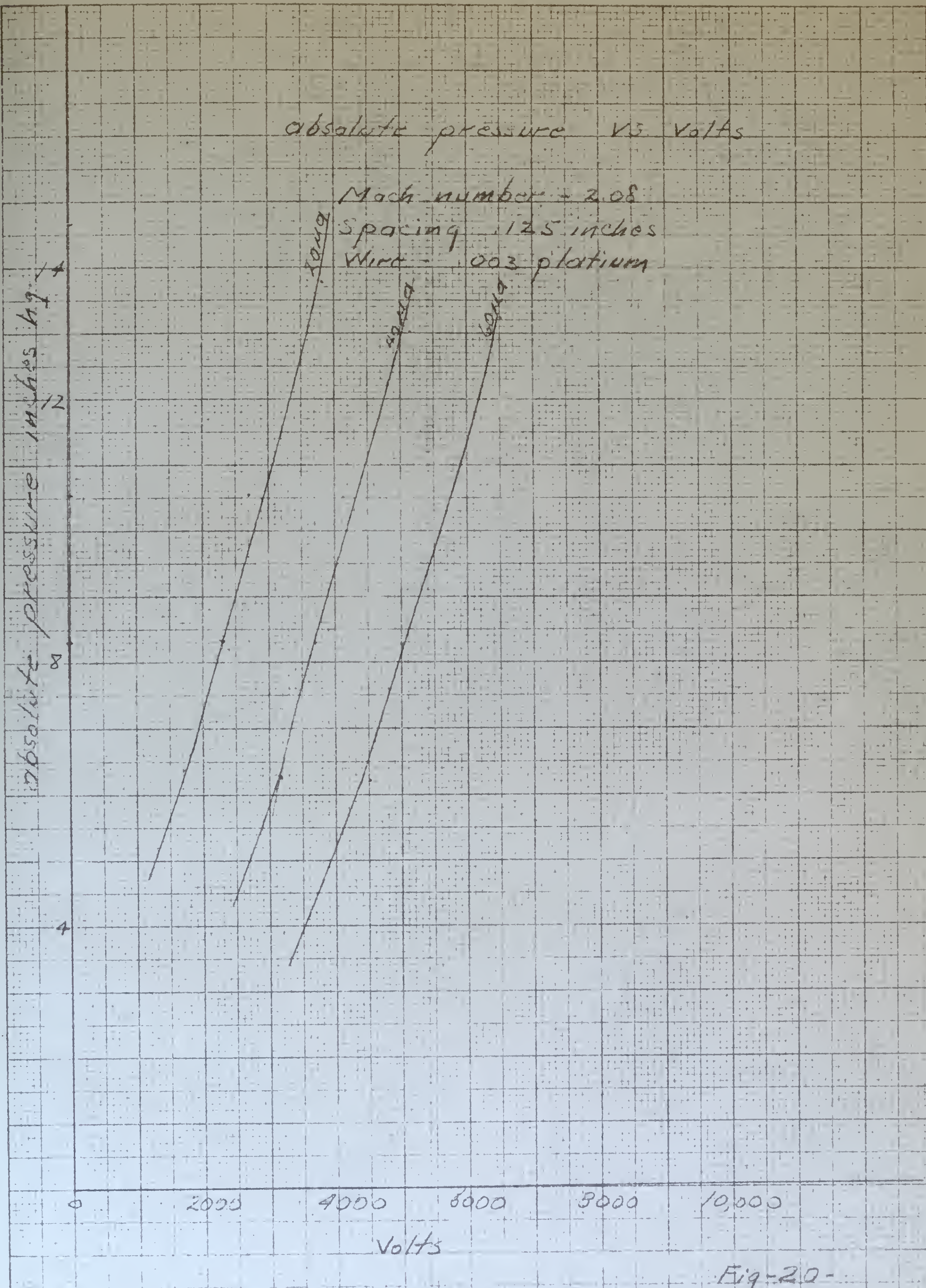
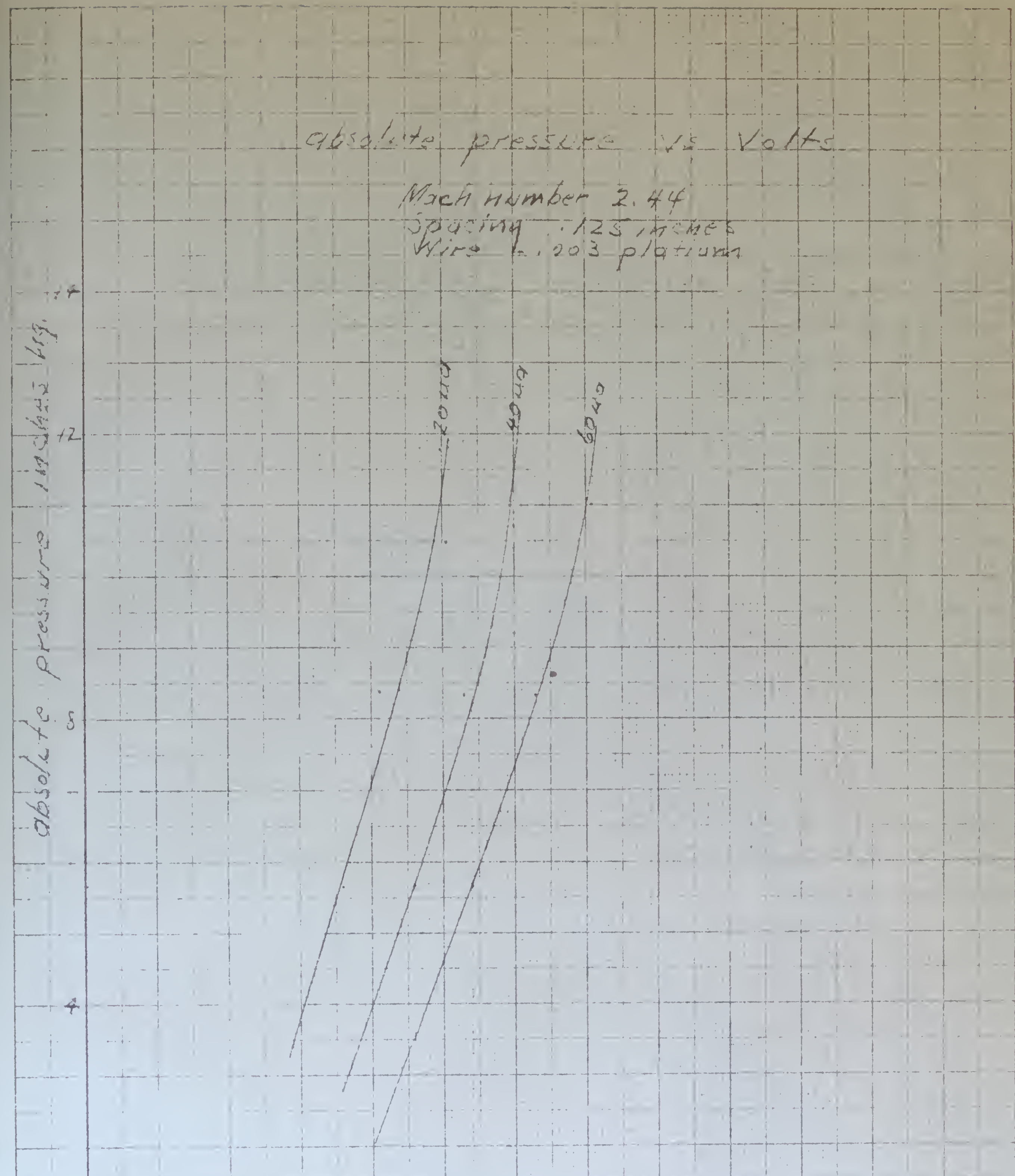

absolute pressure VS Volts
Mach number - 2.08
Spacing .125 inches
Wire - .003 platinum
3000
4000
6000
absolute pressure inches hg.
12
8
4
0
2000
4000
6000
8000
10,000
Volts

Fig-20-


absolute pressure vs Volts
Mach number 2.44
Spacing .125 inches
Wire .003 platium
absolute pressure inches Hg.
12
8
4
2000
4000
6000
0
2000
4000
6000
8000
10000
Volts
Fig-21-

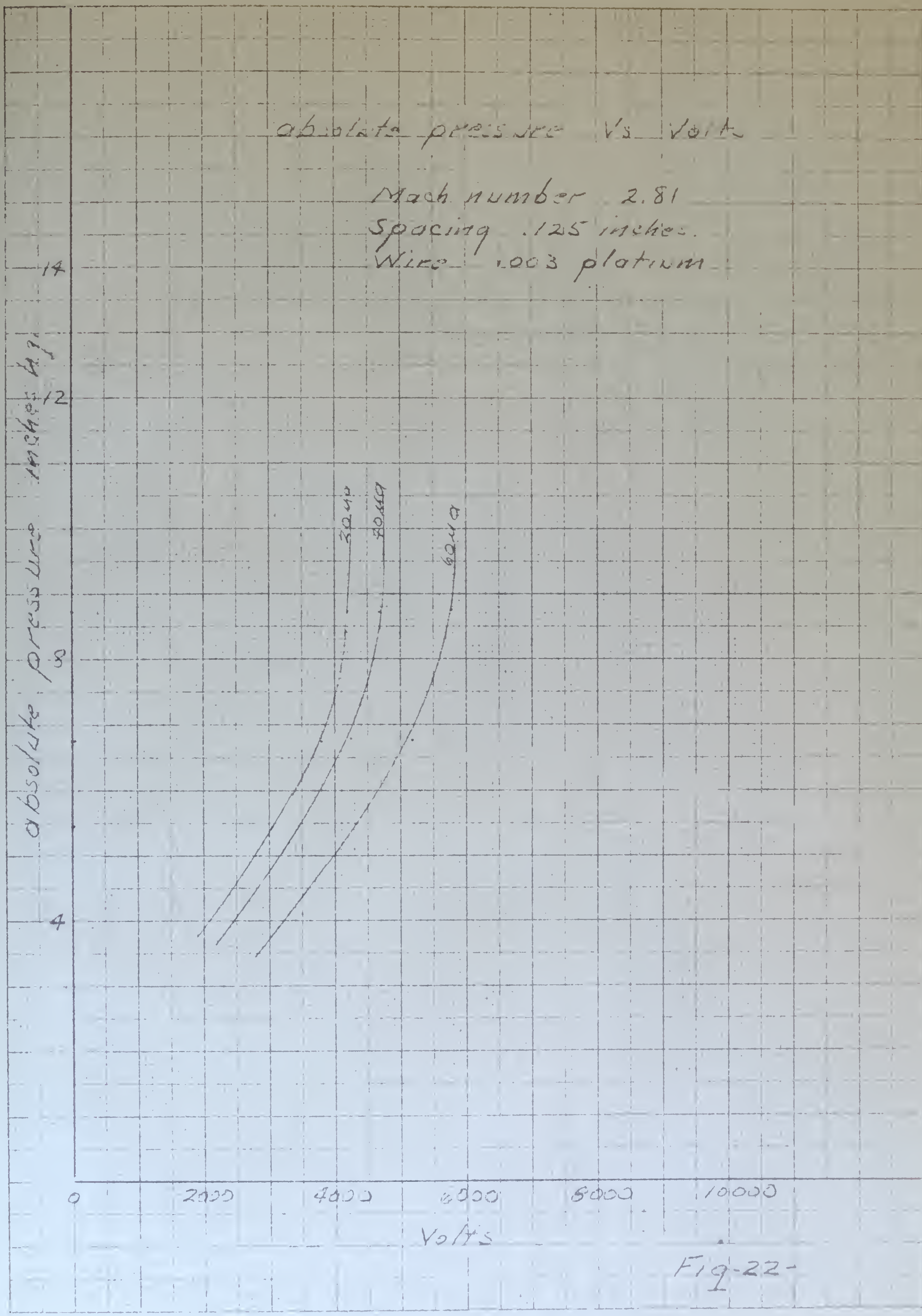

absolute pressure Vs Volt
Mach number 2.81
Spacing .125 inches
Wire .003 platium
absolute pressure inches Hg
14
12
8
4
3040
3040
6040
0
2000
4000
6000
8000
10000
Volts

Fig-22-

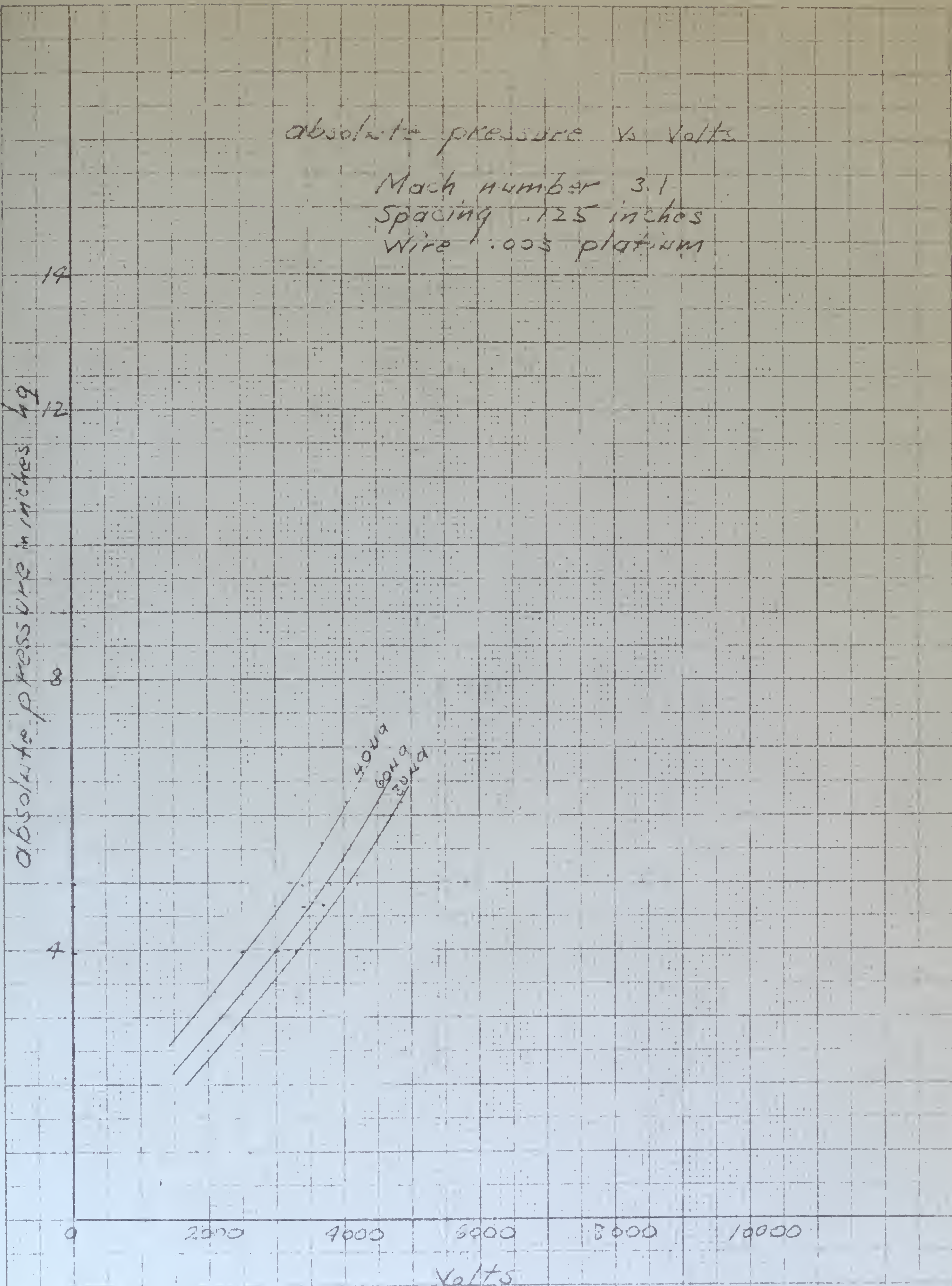

absolute pressure vs Volts
Mach number 3.1
Spacing .125 inches
Wire .003 platinum
absolute pressure in inches Hg
14
12
8
4
0
2000
4000
6000
8000
10000
Volts
40 ua
60 ua
80 ua

Fig - 23 -

Microamps vs Volts at const. abs Pressure
absolute pressure = 5 inches hg.

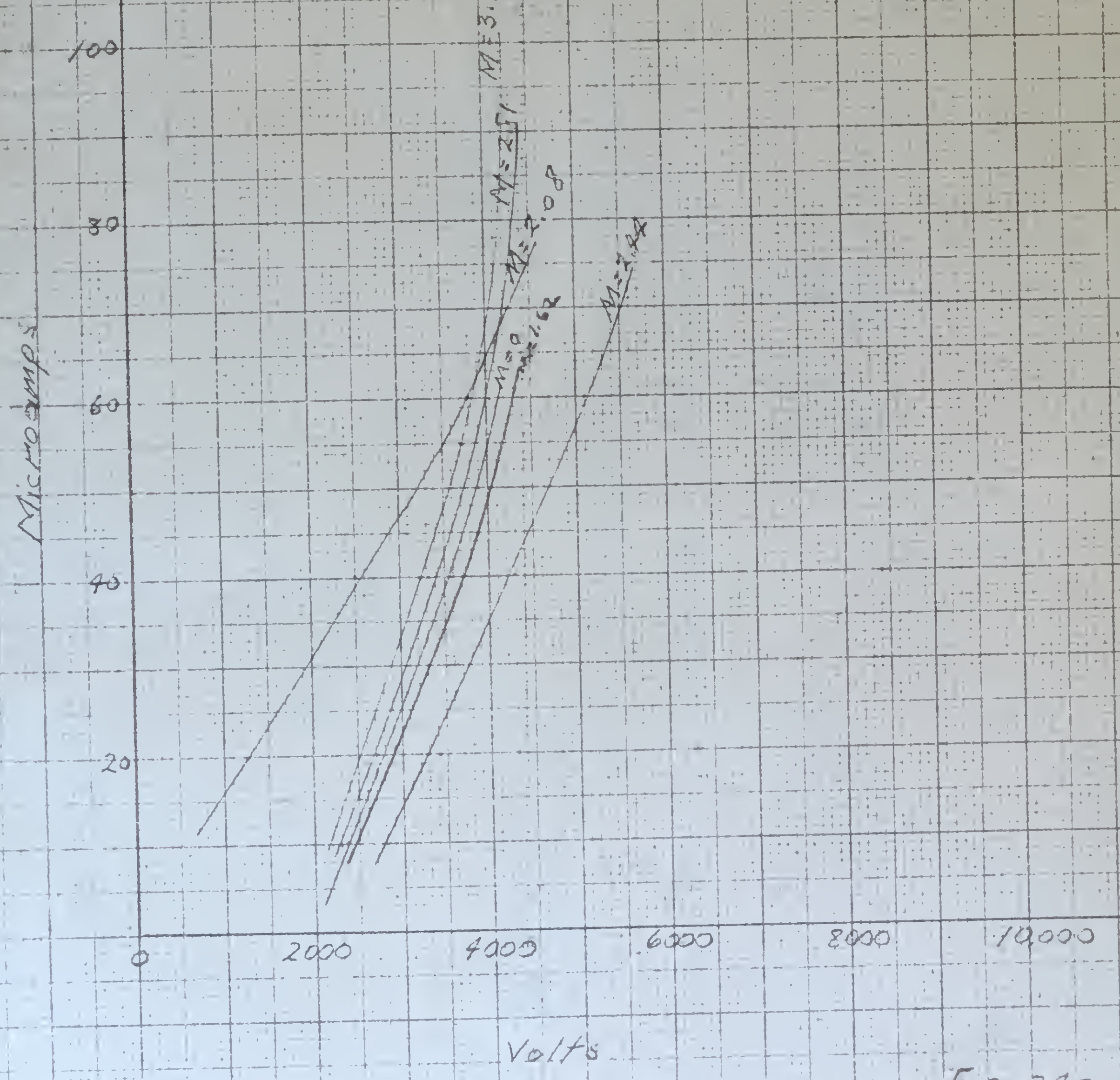
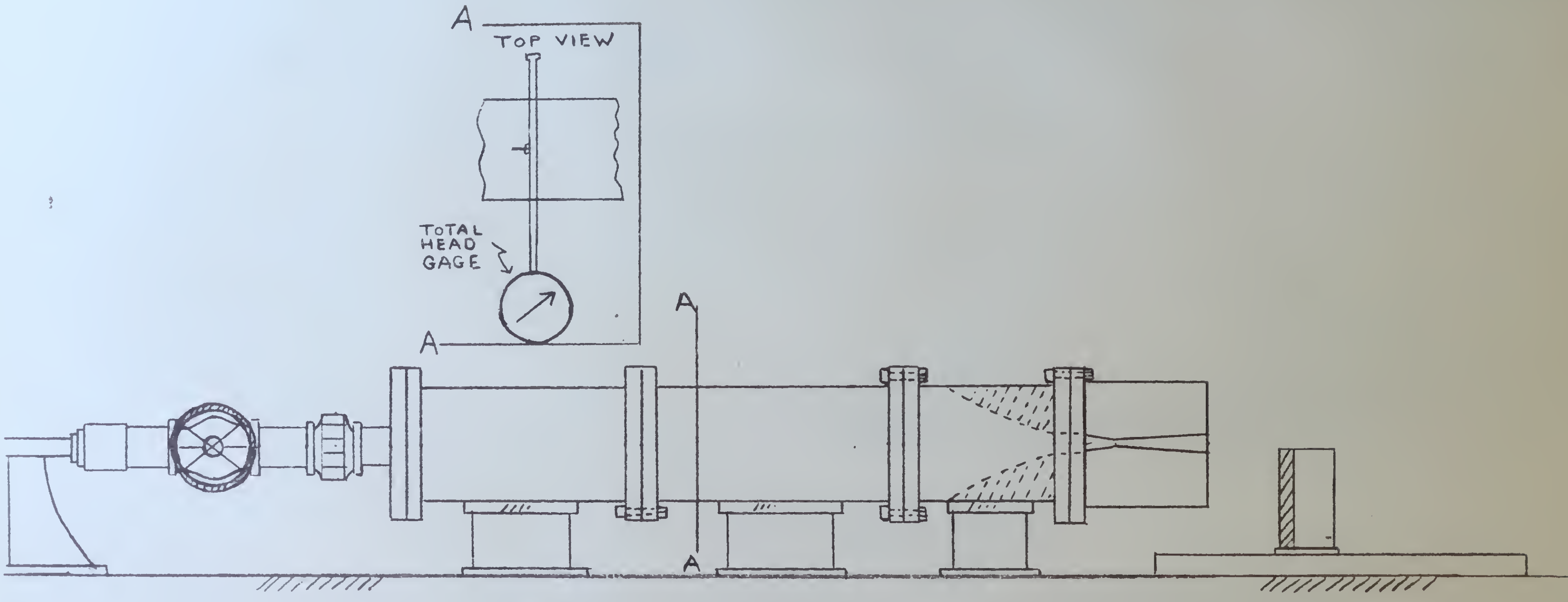


Fig-24-



SIDE VIEW

WIND TUNNEL

SCALE 1/10" = 1"

Fig - 25

NOZZLE BLOCK
DESIGN

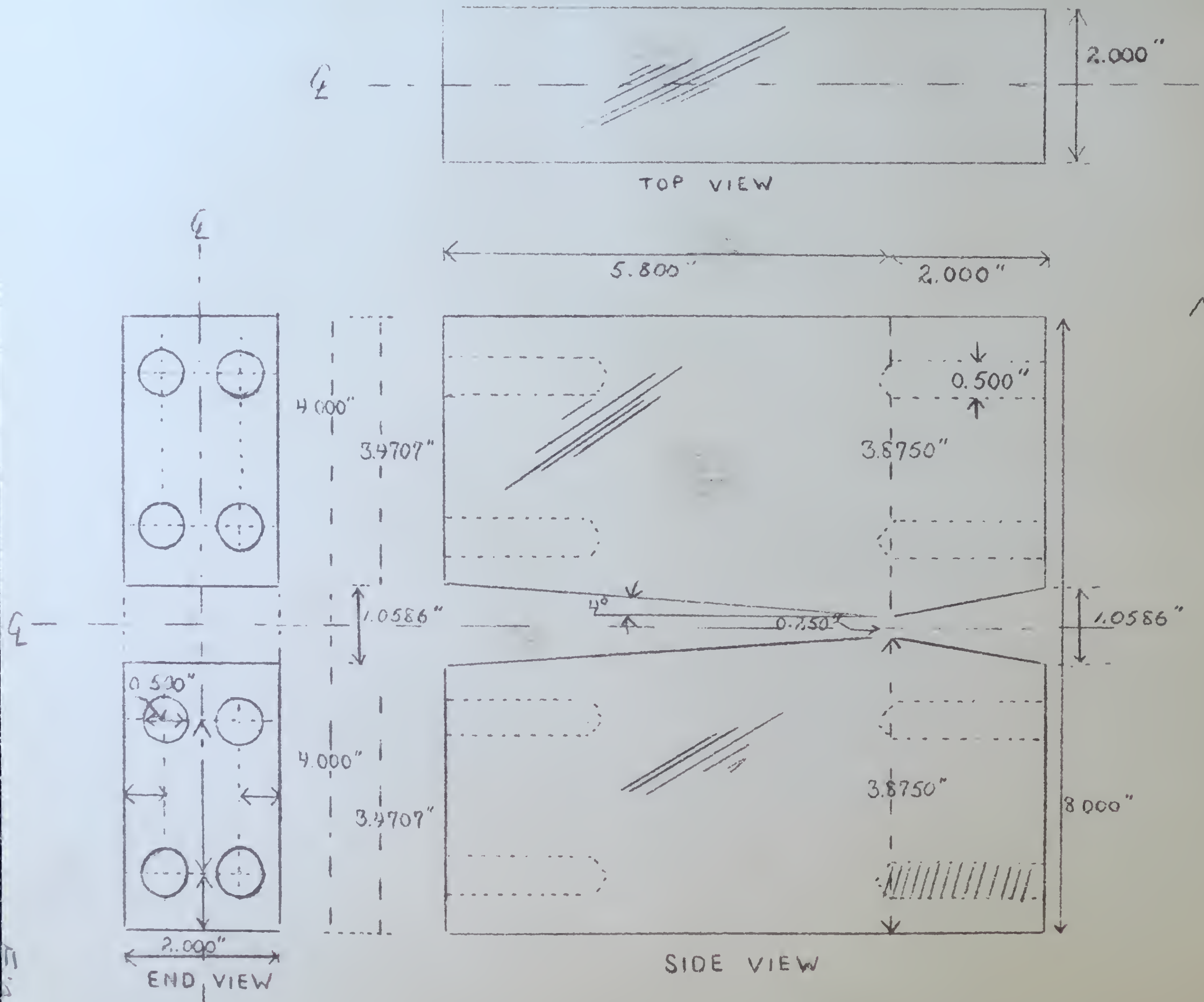
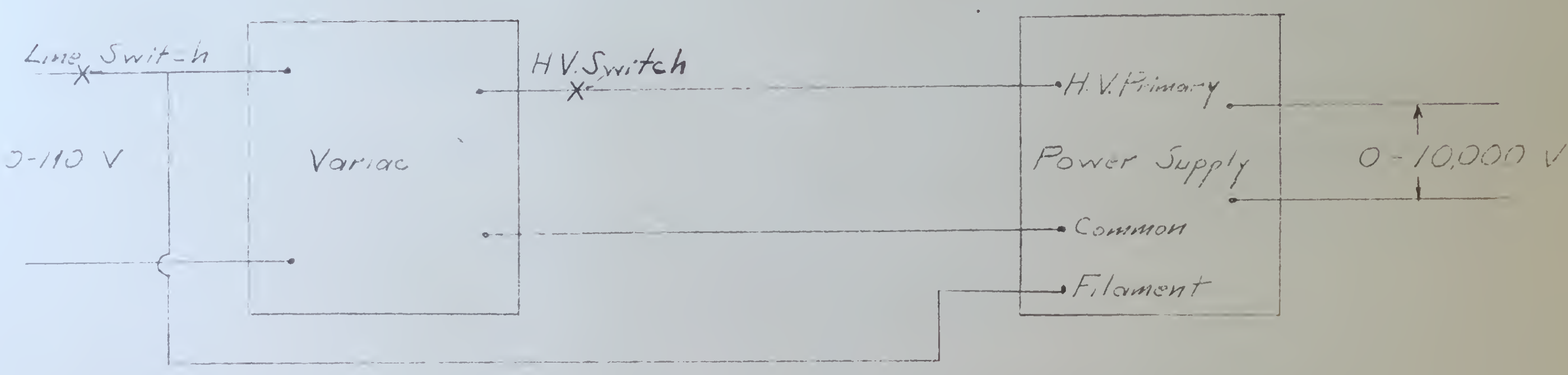
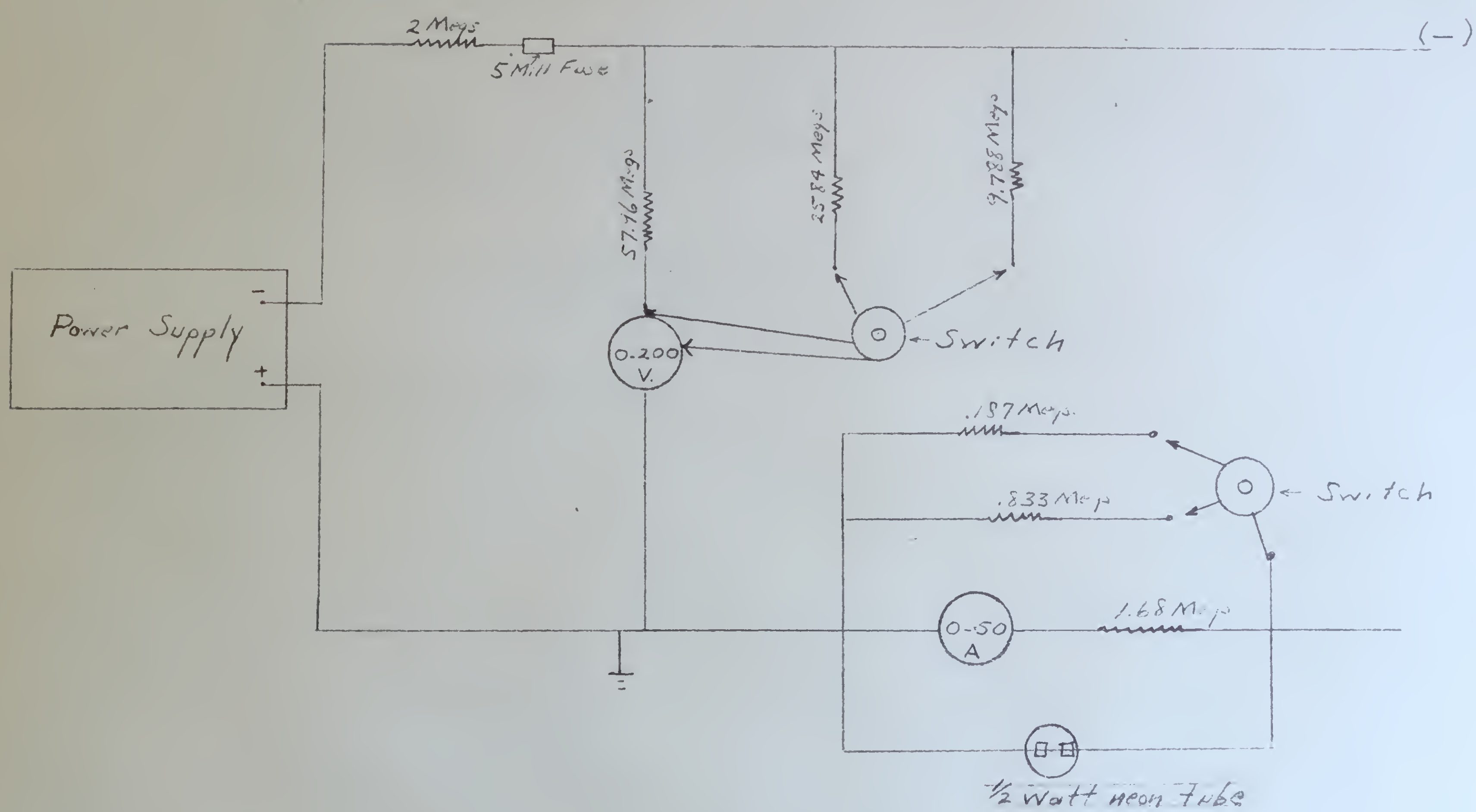


Fig. 26

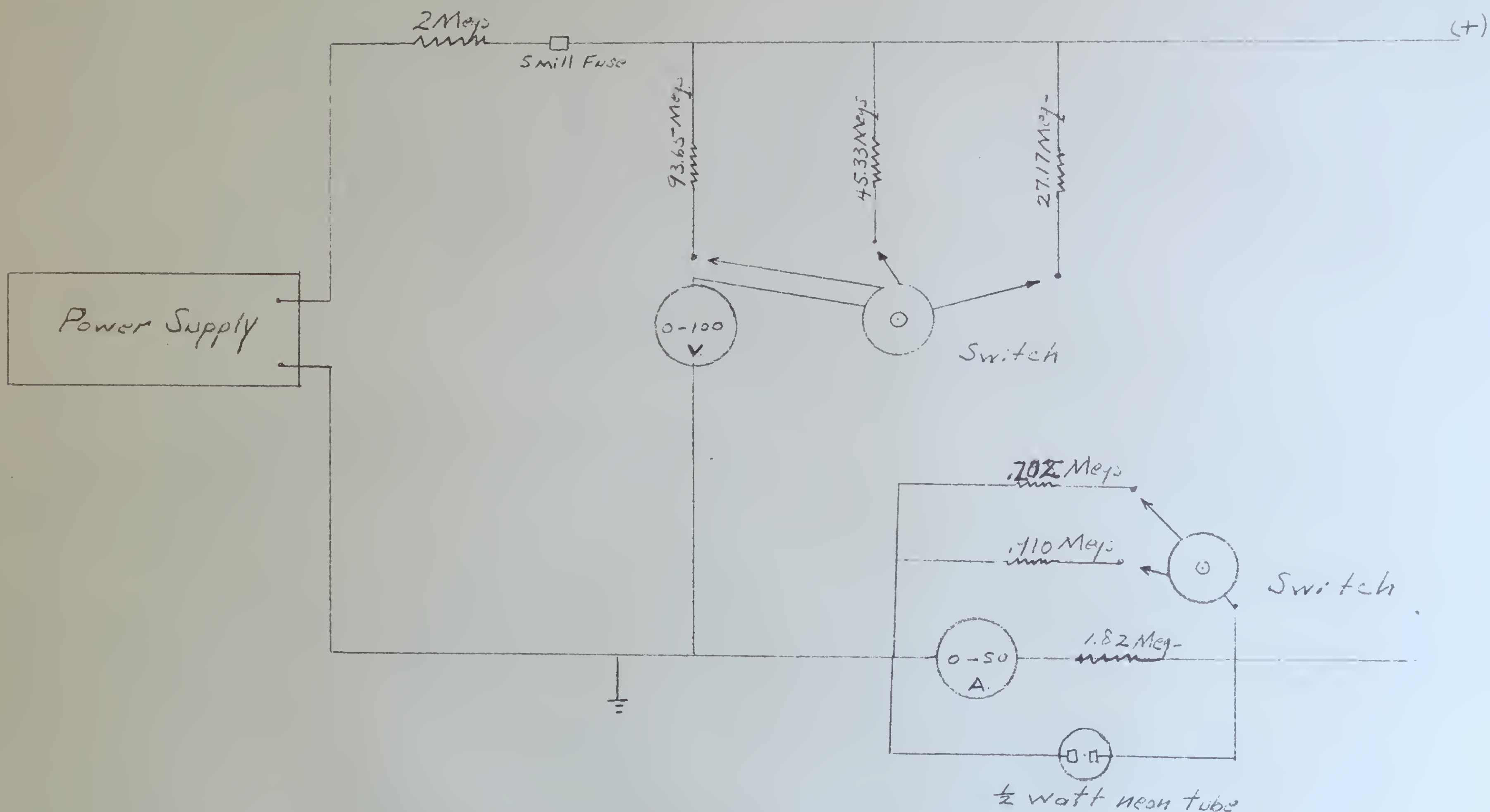


Power Supply

Fig. 27

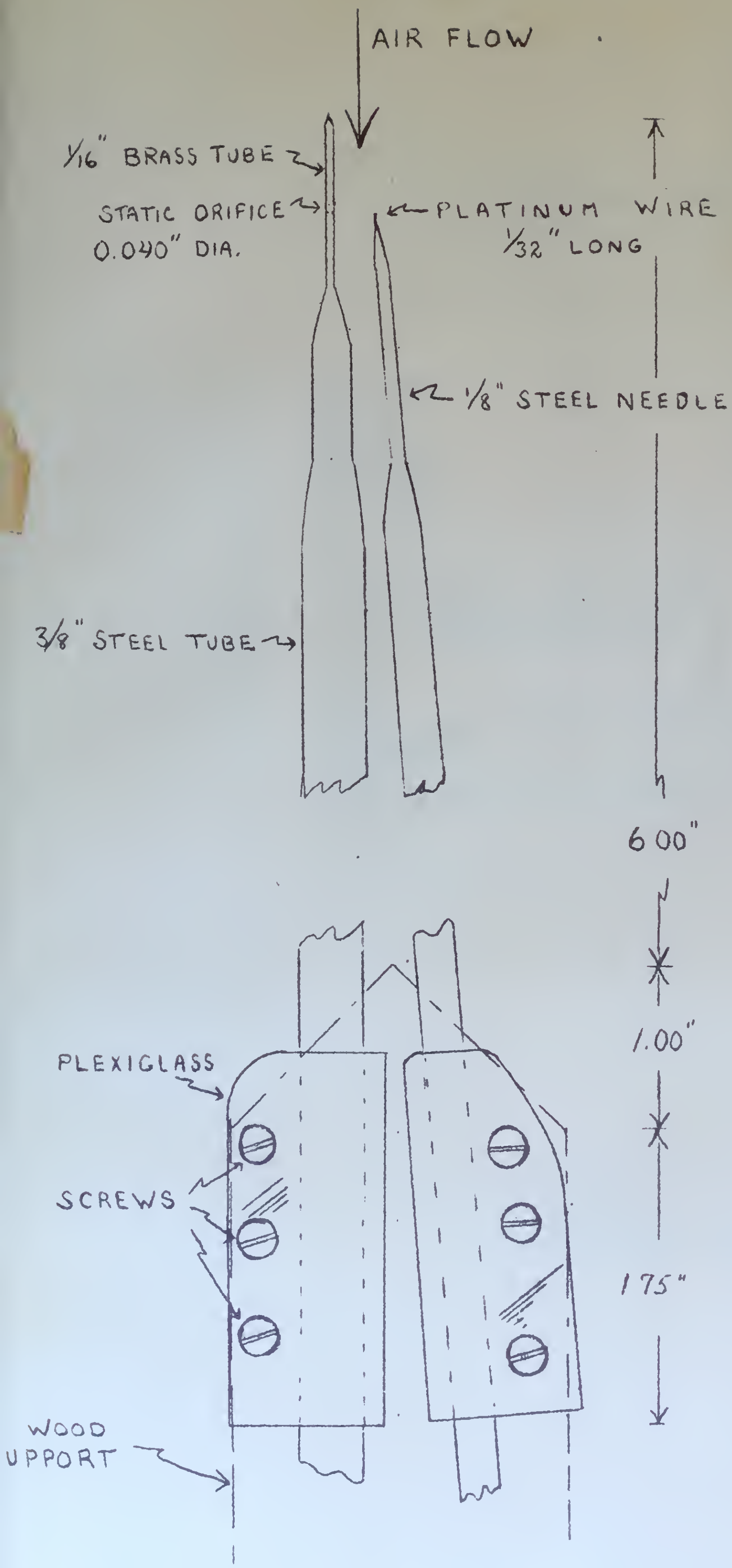

2 Megs
5 Mill Fuse
(–)
57.76 Megs
25.84 Megs
9.788 Megs
Power Supply
–
+
0-200 V.
Switch
.187 Megs.
.833 Megs
Switch
0-50 A
1.68 Megs
½ Watt neon Tube

Circuit # 1



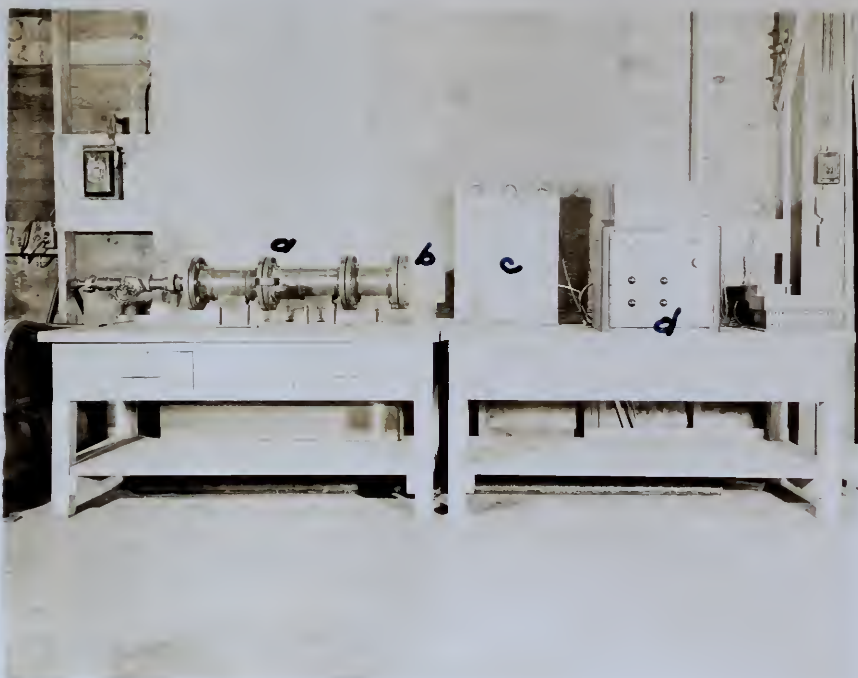
2 Megs
5 mill Fuse
(+)
93.65 Megs
45.33 Megs
27.17 Megs
Power Supply
0-100
V
Switch
.202 Megs
.110 Megs
Switch
0-50
A.
1.82 Meg-
½ watt neon tube

Circuit #2



ARRANGEMENT of the PROBES

WIND TUNNEL & ELECTRONIC EQUIPMENT



a - Stagnation Chamber
b - Nozzle
c - Manometer Board
d - Electronic Equipment

Fig. 31

NOZZLE BLOCKS, PROBES & VACUUM JAR

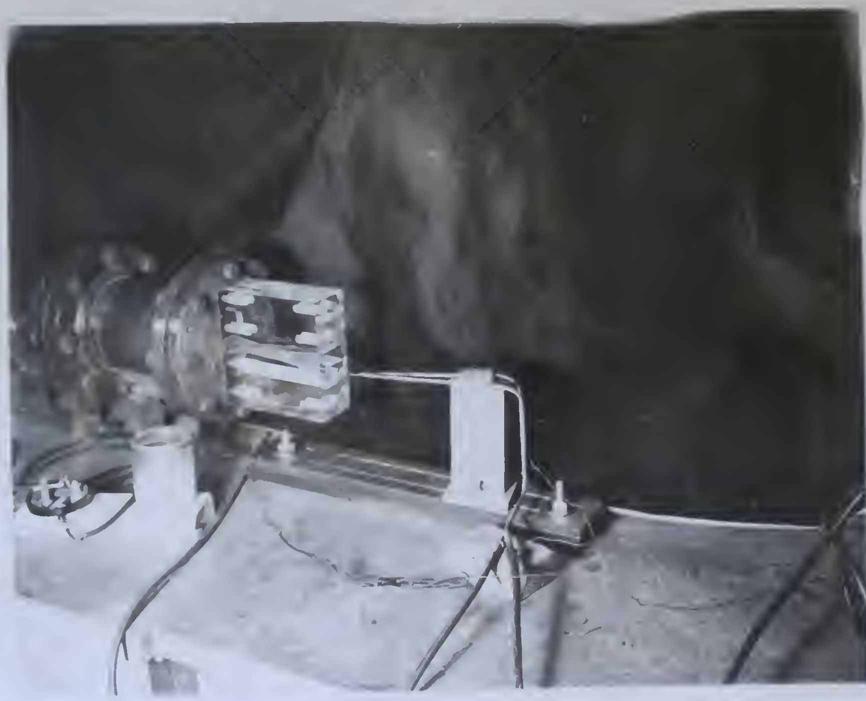
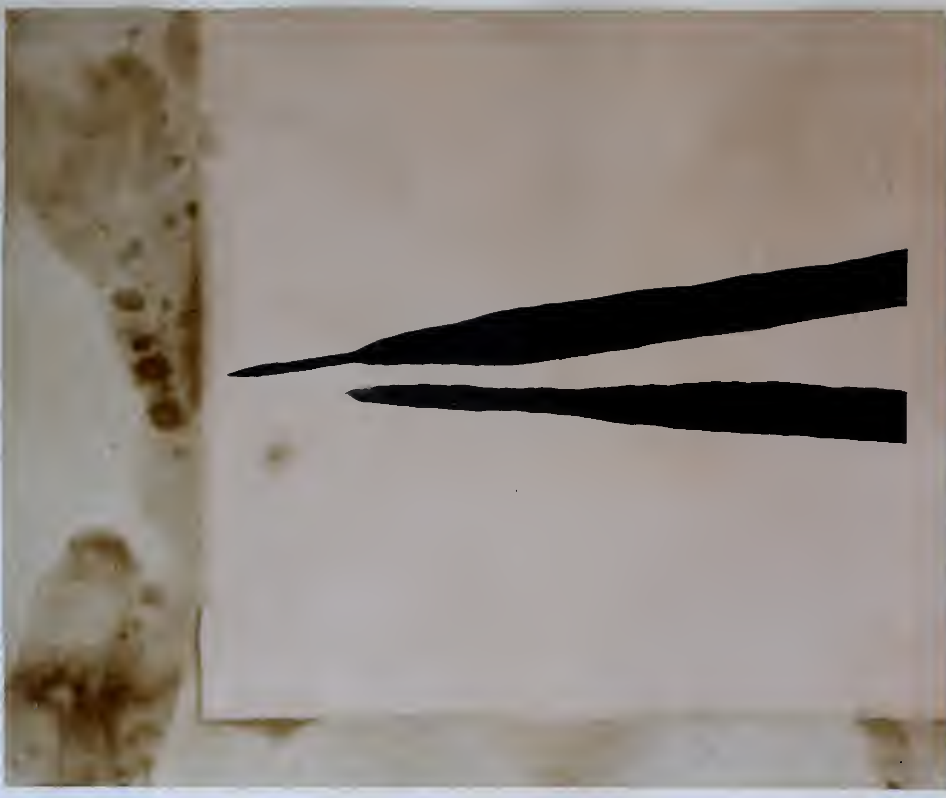


Fig. 32

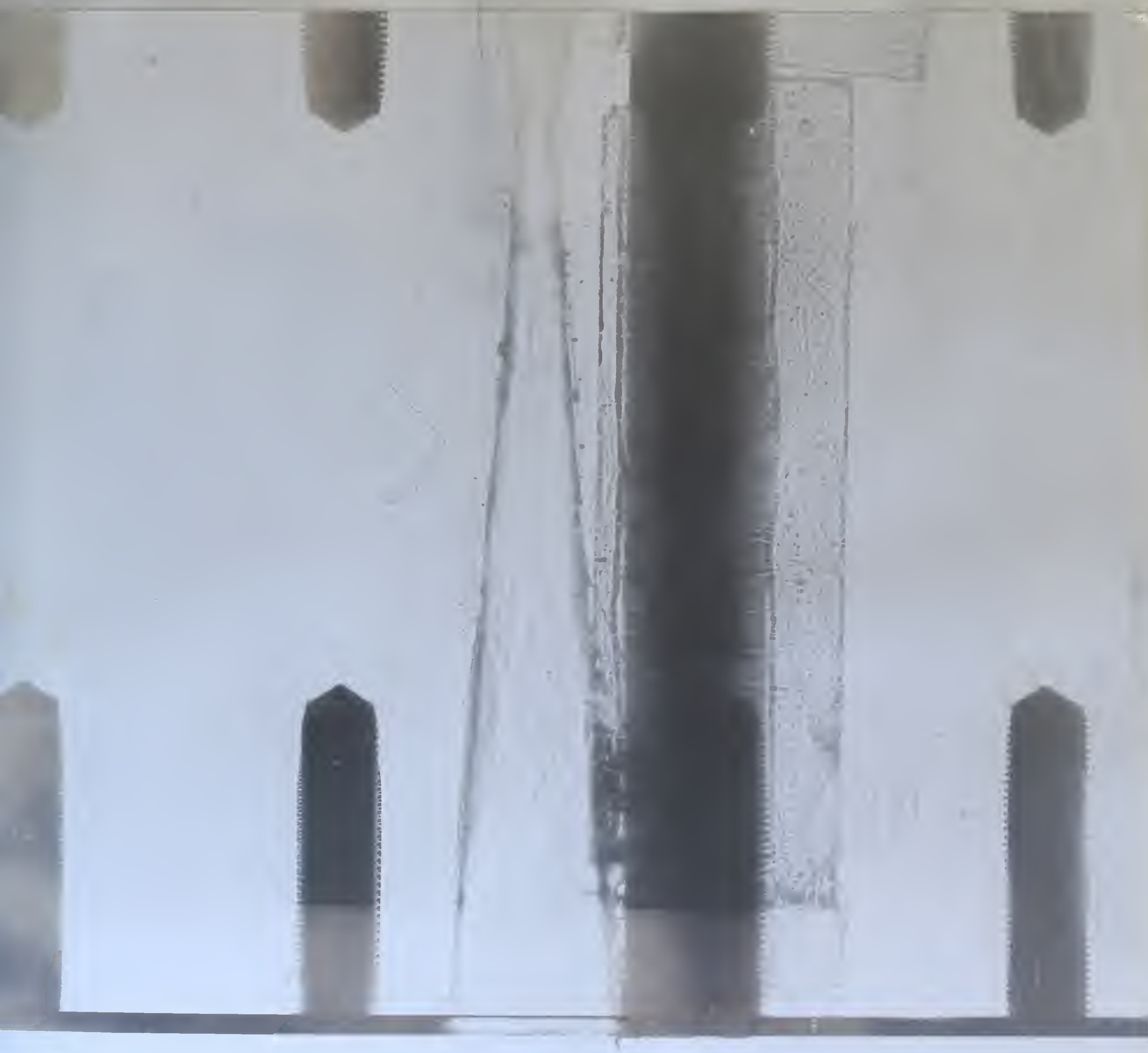


Static Probe

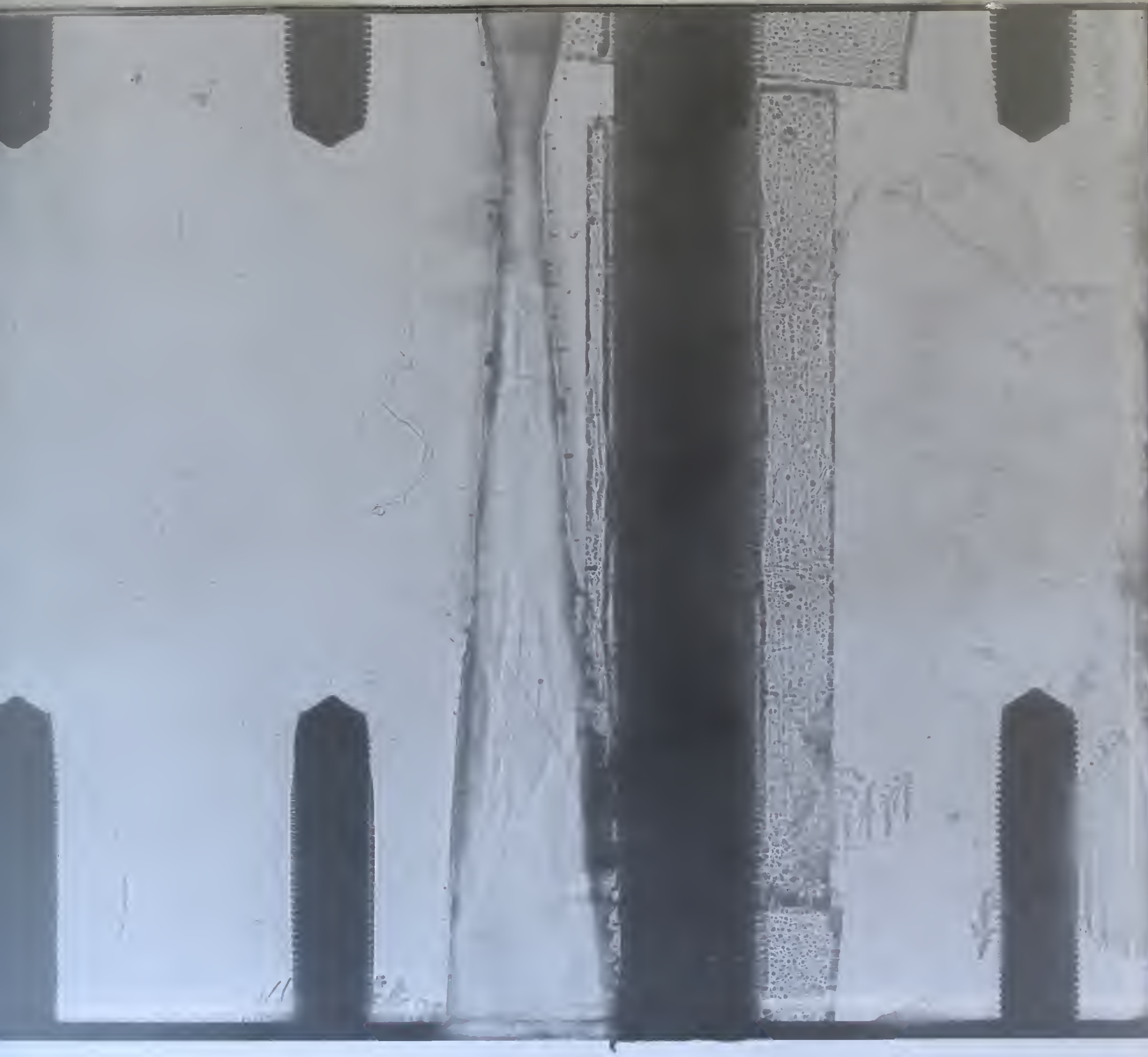
Platium Wire
Probe

PROBES, SPARK PHOTOGRAPH

Fig. 33



M = 0 No Flow Fig. 34



M = 2.81; Stagnation Pressure 90#/in.^{2} gage

Prober Inserted
M = 2.81 Stagnation Pressure 90#/in.^{2} gage

Fig. 36